



## NASA Space Radiation Laboratory (Booster Applications Facility)

### Safety Assessment Document

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## 1. Chapter One, Introduction

### 1.1. Introduction to the BAF SAD

The Booster Applications Facility (BAF) Safety Analysis Document (SAD) presents a basic understanding of the facility's mission, the protections that are afforded the public and the worker's health and safety, and the protection of the environment. An overview of the results and conclusions of the safety analysis is contained within Chapter 2. Comprehensiveness of the safety analysis and appropriateness of the Accelerator Safety Envelope are also addressed in Chapter 2. The environment within which the facility was constructed, those facility characteristics that are safety-related and the methods used in operating the Booster Applications Facility and associated equipment are presented in Chapter 3. Chapter 4 documents the analysis, including the methodology, used for identification and mitigation of potential hazards. Chapter 5 is the policy for the engineered and administrative bounding conditions within which the Collider-Accelerator Department operates the Booster Applications Facility; that is, the policy for an Accelerator Safety Envelope. However, detailed limits prescribed in the Accelerator Safety Envelope are documented in a separate agreement with the Department of Energy. Chapter 6 describes the quality assurance program at the Booster Applications Facility, focusing upon activities that impact protection of the worker, the public or the environment. A description of structural and internal features that facilitate decommissioning of the Booster Applications Facility is presented in Chapter 7. In this Chapter, waste management of radiological and hazardous material generation from a future decommissioning operation is discussed within the context of present-day Department of Energy requirements.

### 1.2. BAF Research Mission

The Booster Applications Facility is a national facility for research in the diverse field of biological effects of high-proton number, high-energy particles. The Booster Applications Facility's design is broad and diverse to allow pursuits of a variety of aspects of the subject. At the same time, the facility is capable of answering the most basic question in this field, which is quantifying the risk to humans in different shielding environments from exposure to ionizing particles in galactic cosmic rays. Although the effect of high-proton number, high-energy particles on living organisms seems to be too complicated to be amenable to computer simulation for risk assessments in different environments, the task is achievable because the effect is divided into four simpler components that are studied independently at the BAF. These four components are in four different scientific disciplines: 1) nuclear physics, 2) atomic physics, 3) molecular and cellular radiobiology and 4) physiologic tissue/organ radiobiology.

Nuclear physics research involves studying nuclear fragmentation and other nuclear interactions of high-proton number, high-energy particles with matter.

Atomic physics research involves ionization-density profiles produced around the track of individual primary or secondary particles.

Molecular and cellular radiobiology research involves biological effects of ionizations at densities produced by products of high-proton number, high-energy particle

interactions, usually studied *in vitro* at the molecular or cellular level. High-proton number, high-energy particles are termed HZE particles.

Physiologic tissue/organ radiobiology research involves response of the integrated biological systems to radiations, studied *in vivo*.

These components in the four different scientific disciplines are studied independently over large ranges of parameters that appear in the actual HZE-particle interaction with living tissue, which allows the various feasible configurations to be adequately simulated. As an example, *in vivo* studies with a single animal with a single beam bring one closer to the risk answer since the example is an integral piece of a well-planned, large set of experiments that span all four related disciplines. The design of the Booster Applications Facility allows independent studies of all four components in the four different scientific disciplines.

### 1.3. Basic Safety, Health and Environmental Protections at BAF

The BAF is classified as a low-hazard accelerator facility, and is subject to the requirements of the DOE Accelerator Safety Order, DOE O 420.2 or its successors. These requirements are promulgated in BNL's [Accelerator Safety Subject Area](#). A low-hazard facility is defined to be one with potential for no more than minor on-site and negligible off-site impacts to people and the environment. The possibility of any off-site impacts or major on-site impacts is highly unlikely due to the physical aspects of the BAF whereby:

- It is dependant upon external energy sources; that is, electric power, that can be easily terminated.
- The primary hazard is prompt ionizing radiation that is limited to regions where the beam is maintained and is in existence only when a beam is present.

The Collider-Accelerator Department has embraced DOE's Integrated Safety Management System as a basic protection for workers and experimenters. Two Laboratory Standards promulgate the requirements of Integrated Safety Management: BNL ESH Standard 1.3.5, Planning and Control of Experiments, and BNL ESH Standard 1.3.6, Work Planning and Control for Operations.

In order to guide operations and maintenance of the accelerators, beam lines and associated systems at the Department level, BNL ESH Standard 1.3.6 is used to:

- Define the scope of work in a Work Permit or establish the applicability.
- Identify the hazards via the Work Permit process and perform a pre-job walk down.
- Use the Work Permit processes to establish hazard controls and required training.
- Provide the pre-job briefing and perform the work according to plan/permit.
- Use the Work Permit feedback process to identify ways to improve next time.

BNL ESH Standard 1.3.5 is used by the Collider-Accelerator staff to guide experiments in order to:

- Determine the concept and scope of the experiment; assess for special requirements, review hazards and safety concerns.
- Develop an experimental plan and identify controls.
- Set up an experiment and obtain Experimental Safety Review Committee concurrence.
- Approve start-up and perform the experiment according to plan.

- Determine ways to improve next time.

Workers and experimenters at the BAF will be working in or near radiological areas. The rules in 10CFR835 establish radiation protection standards, limits and program requirements for protecting individuals from ionizing radiation resulting from the conduct of DOE activities. These requirements are promulgated in [BNL's RadCon Manual](#). Basic radiation protection systems and programs include:

- Access Control System.
- Fixed-location and interlocking area-radiation monitors.
- Shielding, posting and fencing.
- Training and qualifications for radiation workers, experimenters and visitors.
- Personnel dosimeters.
- Radiation Work Permits.
- ALARA reviews of jobs and experiments when needed.
- Daily radiation surveys using portable radiation monitors.
- Control of radioactive materials and sources.

Basic fire protection includes compliance with DOE fire protection guidelines as well as NFPA's guidelines. The fire protection system is integrated with the site-wide system and comprises an automatic fire detection and suppression system that consists of fire-rated walls used to separate fire protection zones, automatic wet-pipe and dry-pipe fire suppression, and rapid response capability coverage by the BNL Fire Department. The means of egress for occupancies is in accordance with NFPA 101.

The environmental policy as set forth by Brookhaven National Laboratory in the Environmental Stewardship Policy is the foundation on which the C-A Department manages significant environmental aspects and impacts. The formal management program is called the C-A Environmental Management System, which complies with ISO 14001. Basic environmental protections that address significant environmental aspects identified by the Environmental Management System include:

- Concrete and iron shields to reduce soil activation and skyshine radiation to as low as reasonably achievable.
- Formal design reviews for modifications.
- Drawing configuration control.
- Domestic water supply equipped with back-flow prevention to isolate the laboratory domestic water supply systems.
- A system to hold-up spilled liquids.
- A system for ventilation.
- Waste-handling training and qualifications.
- Segregation and lock-down of ordinary waste stream, hazardous waste stream and radioactive waste stream.
- Isolation of storm-sewer drain-lines near the experimental area.
- Water-impermeable barriers to prevent rainwater from leaching radioactivity from activated soil.
- Even though tritium levels in cooling water are less than the Drinking Water Standard, the intent of Suffolk County Article 12 Code was followed in the design of cooling water systems and piping that contain trace amounts of tritium.
- Compliance with 40CFR61, Subpart H for airborne emissions.

- Alarms on water systems to detect leaks and alert operations personnel.
- Isolated closed cooling-water systems to reduce the volume of tritiated water.
- Process evaluations and annual reviews of activities by the C-A Department's Environmental Compliance Representative.

## 2. Chapter Two, Summary/Conclusions

### 2.1. An Overview of the Results and Conclusions of the Analysis

A study of site geography, seismology, meteorology, hydrology, demography and adjacent facilities that are impacted by the BAF shows:

- About 30% of the BNL site is developed with buildings and roads and the balance is undeveloped Pine Barrens forest.
- It is the consensus of seismologists that no significant earthquakes are to be expected in the near future.
- The climate is temperate.
- The Upper Glacial aquifer is a widely used public and private water supply.
- That radiation from Booster Applications Facility operations will not affect occupants located at the closest occupied non-BAF facilities.

The design criteria and as-built characteristics for the BAF, and its supporting systems and components with safety-related functions are:

- The Booster Applications Facility is essentially an extraction system in the Booster ring followed by a beam line, target area and beam stop, with adjacent experimental and utility support buildings.
- The design criteria provide the most versatile experimental beam and range of energies and intensities practicable. Particles range from protons to Au ions. Nucleon energies range from 0.04 to 3.07 GeV, and intensity ranges from  $10^3$  to  $10^{11}$  ions per pulse.
- There are two engineered Booster Applications Facility safety significant systems: the fire protection system and the access controls system for radiation safety.
- The design criteria for the Access Control System are that it is redundant, failsafe and has backup, backup is sometimes termed “reach-back,” plus it prevents radiation levels from rising to unacceptable levels.
- The design criteria for the fire protection system are that alarms and sprinklers are supervised for circuit trouble and they report to the site Fire/Rescue Group, building occupants can hear and/or see alarms throughout the facility, and manual fire alarm pull boxes are located at each exit.

Features that minimize the presence of hazardous environments and ensure chemical and radiation exposures are kept ALARA during operation, maintenance and facility modification are:

- For radiation: radiation interlocks, gate interlocks, key trees, bio-identification system, crash cords, audible and visual warnings for beam, fully enclosed beam line and Target Room, shielding, fencing and posting.
- For airborne hazards: hoods and individual laboratory ventilation, short-lived airborne radioactivity re-circulated in the beam line, air emissions from Target Room vented to the outside, and airflow direction from Support Laboratories into Target Room.
- For ALARA: caps over activated soil, multi-leg penetrations and labyrinths, re-entrant cavity with movable shield at face of beam stop, and sample translator or relay apparatus when applicable.
- For electrical safety: covers on all conductors, sectionalizing gate dividing the beam line and Target Room, compliance with the National Electric Code for all electrical

distribution systems, fused circuitry in experimental equipment, and emergency-off controls for power.

- For life-safety and fire protection: manual fire alarm stations, smoke detection, fire alarms, sprinkler protection, fire-hose standpipes, exits that meet the Life Safety Code, emergency lighting, and fire extinguishers.
- For liquid effluents: sump and sump alarm, drains connected to Sanitary Sewage System, cooling water make-up alarms, no outdoor tritiated water piping, closed tritiated cooling-water system, and back-flow preventers on supply water.
- For biological safety: Biosafety Level 2 design, Class 2, Type A biological safety cabinets, HEPA filtered air circulation in the animal laboratory, separate ventilation in the cell laboratory, and poured-resinous, seamless floors and washable walls in the animal laboratory.

The organizational and management structure the Collider-Accelerator Department and a delineation of responsibilities for safety related actions assure safe operation of the Booster Applications Facility. Controls for routine operations and emergency conditions are located in the Main Control Room in Building 911, a control room that is staffed around-the-clock by qualified staff during operations. Procedures for routine operation and emergency conditions are delineated in the Collider-Accelerator Operations Procedure Manual, which is a controlled document.

Specific operations controls that prevent or mitigate accidents are the beam-loss monitoring systems. The purpose of these machine protection systems is to minimize beam loss and to help provide the required beam on target. The Collider-Accelerator Department management requires that inadvertent beam loss occur at levels that are as low as reasonably achievable with operational, economic and community factors taken into account. Specific operations procedures and protocols that prevent or mitigate accidents include sweep procedures for beam enclosures, Access Control System testing procedures, beam-loss ALARA procedures, fire-protection system testing, soil-cap inspection procedures, experimental safety check-off lists, radiation safety check off-lists, and work planning procedures.

Based on analysis, the risk of a serious injury from fire, radiation and electrical hazards at Booster Applications Facility is considered insignificant. This is due to controls that are employed for hazard mitigation. A study of the credible challenges to controls and estimates of consequences in the event of corresponding failure showed that the risk of injury was unlikely. The credible maximum bounding accident scenarios for the BAF and experiments show less than the design goal of 20 mrem per event to individuals outside the shield. Risks to workers, the public and environment are considered insignificant for routine operations.

## 2.2. Comprehensiveness of the Safety Analysis

The BAF SAD is consistent with DOE Orders. It closely follows the prescription for an SAD given in [Draft Accelerator Safety Implementation Guide for DOE O 420.2, Safety of Accelerator Facilities, Office of Science, Department of Energy, May 1999](http://www.rhichome.bnl.gov/AGS/Accel/SND/420Guide/Guide420.pdf).<sup>1</sup>

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<sup>1</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/420Guide/Guide420.pdf>

The fire protection system and the Access Control System are identified as safety significant. The Department's shielding policy is clearly stated.<sup>2</sup> Optimization methods are used to assure that occupational exposure is maintained ALARA in developing and justifying facility design and physical controls.<sup>3</sup> Major hazards are identified and adequate controls are described, including environmental controls to protect activated soil from rainwater infiltration.<sup>4, 5, 6, 7, 8, 9</sup>

Models used for dosimetric predictions in the SAD are described and are to be verified against measurements made during commissioning. A list of environmental aspects for the BAF operations is enumerated. The BAF SAD clearly documents the safety and health aspects of all portions of the facility including the beam line, Target Room and Support Laboratories. The C-A Department organizational structure and ESH programs for commissioning and operation of BAF are adequately described in the SAD.

### 2.3. Appropriateness of the Proposed Accelerator Safety Envelope

Using Chapter 4 of the BAF SAD, its associated risk assessment forms in Appendix 9, and results of the [Environmental Assessment for the BAF](#), the Accelerator Safety Envelope (ASE) was developed according to requirements set forth in the BNL SBMS Subject Area, Accelerator Safety.

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<sup>2</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/BAF/BAFSADAppendix10.doc>, Appendix 10, Shielding Policy

<sup>3</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/BAF/BAFSADAppendix6.doc>, Appendix 6, 10CFR835 ALARA Design Document for BAF

<sup>4</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/BAF/BAFSADAppendix1.pdf>, Appendix 1, Estimates of Radiological Quantities Associated with the Booster Applications Facility

<sup>5</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/BAF/BAFSADAppendix3.pdf>, Appendix 3, BAF Beam Loss Assumptions

<sup>6</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/BAF/BAFSADAppendix4.pdf>, Appendix 4, BAF Clean Air Act Assessment (NESHAPS)

<sup>7</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/BAF/BAFSADAppendix7.pdf>, Appendix 7, Estimate of Induced Activity Near the BAF Beam Dump

<sup>8</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/BAF/BAFSADAppendix8.pdf>, Appendix 8, Fire Hazard Analysis for BAF

<sup>9</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/BAF/BAFSADAppendix9.pdf>, Appendix 9, Qualitative Risk Assessment

### 3. Chapter Three, Site, Facility and Operations Description

#### 3.1. Characterization of the Booster Applications Facility Site Location

The site geography is such that BNL is located near the center of Suffolk County, Long Island, about 60 miles east of New York City. Most of the principal facilities are located near the center of the BNL's 5,265-acre site. The developed area is approximately 1,650 acres, consisting of about 500 acres originally developed by the Army, as part of Camp Upton. The developed area is still used for offices and other operational buildings; 200 acres occupied by large, specialized research facilities; 550 acres occupied by outlying facilities, such as the Sewage Treatment Plant, research agricultural fields, housing, and fire breaks; and 400 acres of roads, parking lots, and connecting areas. The balance of the site, approximately 3,600 acres, is largely wooded and it represents native pine barren ecology. See Figures 3.1.a, 3.1.b and 3.1.c.

Figure 3.1.a Site Overview

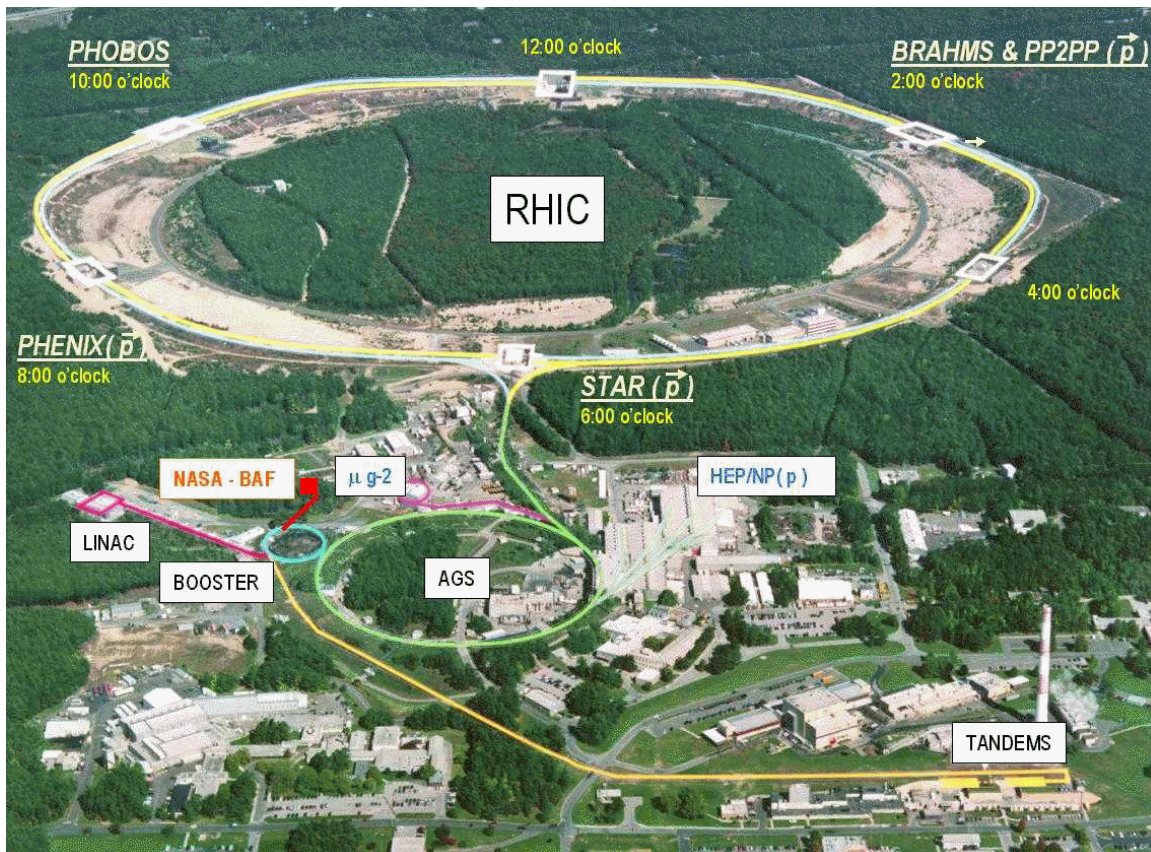


Figure 3.1.b Booster Applications Facility Site Plan View

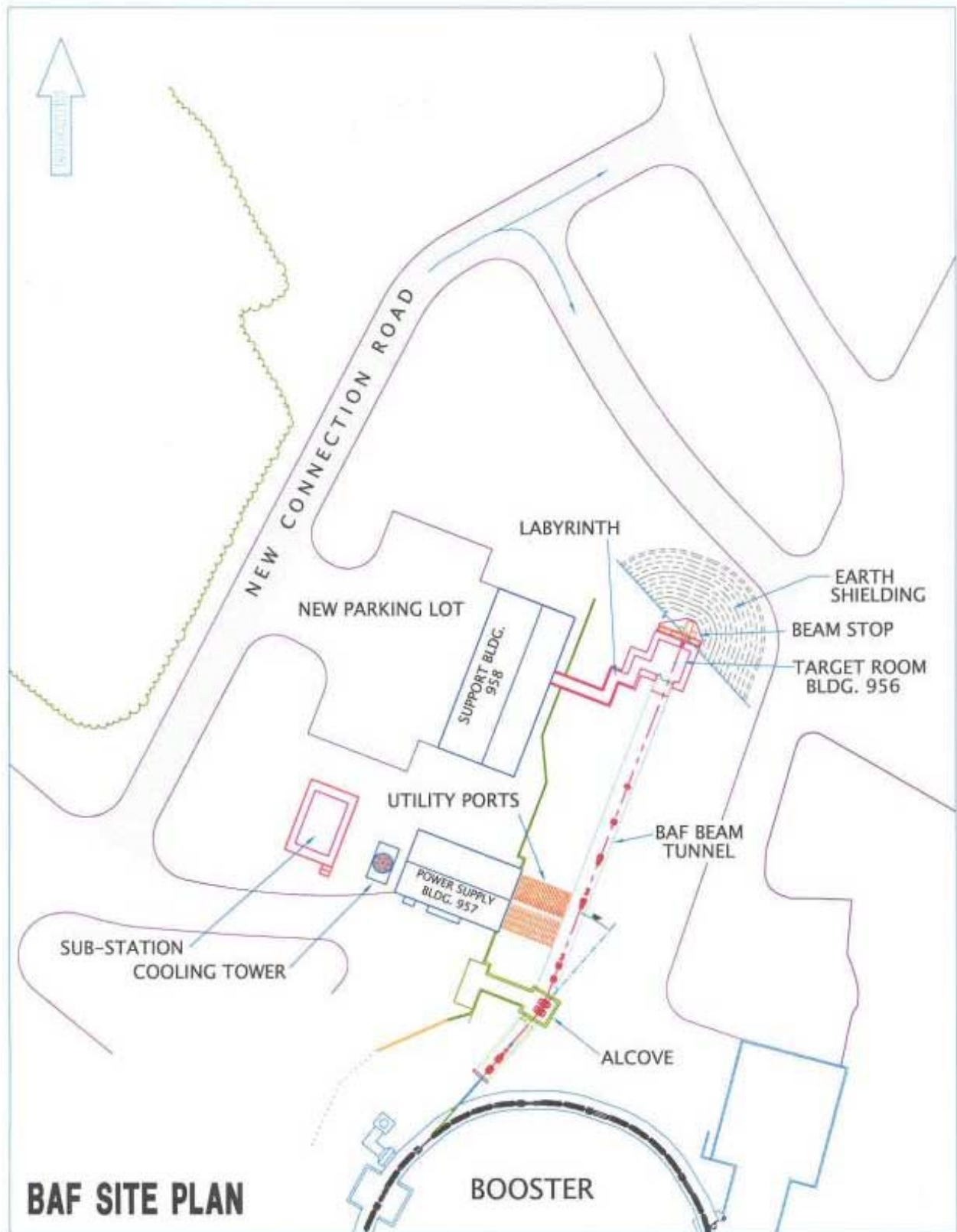
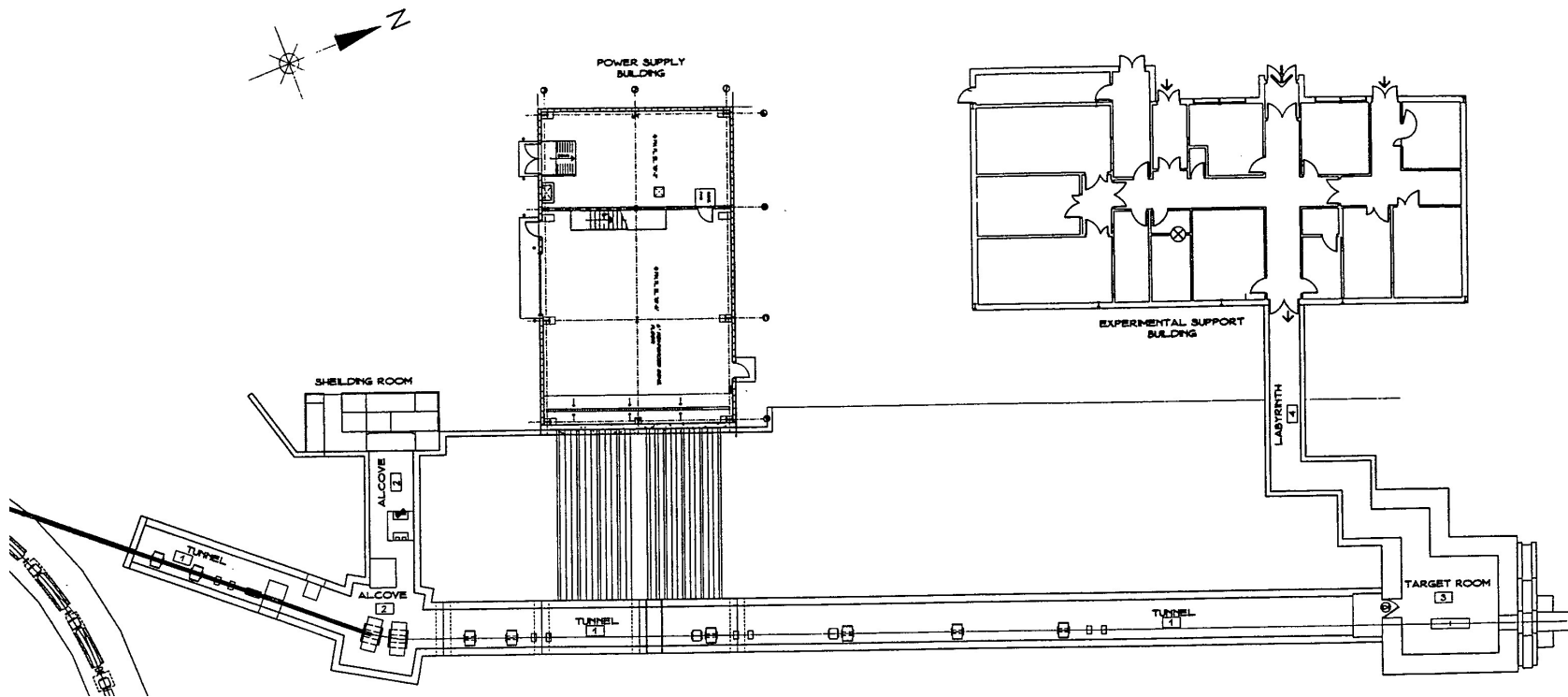


Figure 3.1.c Booster Applications Facility Plan View



The probable occurrence of an earthquake sufficiently intense to damage buildings and structures in the BNL area has been thoroughly investigated as part of the planning for construction of the Relativistic Heavy Ion Collider. It is the consensus of seismologists that no significant earthquakes are to be expected in the near future. No earthquake has yet been recorded in the BNL area with intensity in excess of modified Mercalli III, equivalent to 1 to 8 cm/s<sup>2</sup> acceleration.<sup>10</sup> However, since Long Island lies in a Zone 1 seismic probability area, it has been assumed that an earthquake of Intensity VII, 5.6 on the Richter scale could occur, which is negligible damage of good design and construction.<sup>11</sup> Liquefaction potential of soils at BNL for such an event is negligible given existing soil density and saturation parameters. Thus, structural stability should remain through an event of this magnitude. No active earthquake-producing faults are known in the Long Island area.<sup>12</sup>

The meteorology is such that prevailing ground level winds at BNL are from the southwest during the summer, from the northwest during the winter, and about equal from these two directions during the spring and fall. Recent meteorological data show the total annual precipitation to be 50 inches. The monthly mean temperature is about 54 °F, ranging from a monthly mean low temperature of 32 °F in January to a monthly mean high temperature of 76 °F in July. The average annual mean temperature shows a continuing trend of increasing annual temperatures. In general, annual mean temperature at BNL has increased 1.9 °F over the last 50 years, compared to a worldwide average surface temperature increase of 0.55 °F.

The hydrology is such that the BNL site is underlain by approximately 1,300 feet of unconsolidated Pleistocene and Cretaceous sediments overlying Precambrian bedrock. The unconsolidated sediments, subdivided from youngest to oldest, are as follows:

- Upper Pleistocene deposits or Upper Glacial aquifer.
- Gardiners Clay or confining unit.
- Magothy Formation or Magothy aquifer.
- Raritan Formation or Raritan Clay confining unit and Lloyd aquifer.

Detailed discussions on these formations can be found deLaguna 1963, Faust 1963, Lubke 1964, Warren 1968, and Geraghty and Miller 1996 listed in the References.

The Upper Glacial aquifer is widely used on Long Island for both private and public water supply. Drinking water and process water supplies at BNL are obtained exclusively from the Upper Glacial aquifer. The Laboratory currently operates six potable water supply wells that can be pumped at rates of 1,200 gpm, and 5 process supply wells that can be pumped at rates between 50 and 1,200 gpm. During maximum water usage at BNL, up to 6 MGD are pumped from the Upper Glacial aquifer. Most of this water is returned to the aquifer by way of recharge basins or discharge of STP effluent to the Peconic River. Groundwater in the Upper Glacial aquifer beneath BNL generally exists under unconfined conditions. However, in the areas along the Peconic

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<sup>10</sup> U.S. Department of Energy. 1992. Environmental Assessment, Relativistic Heavy Ion Collider at Brookhaven National Laboratory, Upton, New York. DOE/EA# 0508. January 1992.

<sup>11</sup> Pepper, S. 1992. "Seismic Event Prediction," Memorandum to T. Sperry. August 6, 1992.

<sup>12</sup> U.S. Department of Energy. 1978. Final Environmental Impact Statement, Proton-Proton Storage Accelerator Facility (ISABELLE). DOE/EIS# 0003. August 1978.

River where low permeability near surface silt and clay deposits exist, semi-confined conditions may occur. Depth to groundwater varies from several feet below land surface within the lowlands near the Peconic River, to as much as 75 feet in the higher elevation areas located in the central and western portions of the site. The depth to groundwater in the Booster Applications Facility area is approximately 25 feet below land surface. Available geologic data collected during the installation of nearby wells, indicates the Booster Applications Facility area is underlain by predominantly medium to coarse-grained sand and fine gravel.

The Long Island aquifer system has been designated by the U.S. EPA as a Sole Source Aquifer System, pursuant to Section 1424(e) of the Safe Drinking Water Act. Groundwater in the sole source aquifers underlying the BNL site is classified as "Class GA Fresh Groundwater" by the State of New York (6NYCRR Parts 700-705). The best usage of Class GA groundwater is as a source of potable water supply. As such, federal drinking water standards, NYS Drinking Water Standards and NYS Ambient Water Quality Standards for Class GA groundwater are used as groundwater protection and remediation goals.

For drinking water supplies, the federal maximum contaminant levels (MCLs) set forth in 40 CFR 141 and 40 CFR 143 apply. The Laboratory maintains six wells and two water-storage tanks for supplying potable water to Laboratory community. In NYS, the Safe Drinking Water Act requirements pertaining to the distribution and monitoring of public water supplies are promulgated under Part 5 of the NYS Sanitary Code, which is enforced by the SCDHS as an agent for the NYS Department of Health. These regulations are applicable to any water supply that has at least five service connections or regularly serves at least 25 individuals. The Laboratory supplies water to a population of approximately 3,500 employees and visitors and must comply with these regulations. In addition, DOE Order 5400.5, Radiation Protection of the Public and Environment, establishes Derived Concentration Guides for radionuclides not covered by existing federal or state regulations.

The BNL groundwater surveillance program uses wells, which are not utilized for drinking water supply, that are designed to monitor research and support facilities where there is a potential for environmental impact, or in areas where past waste handling practices or accidental spills have already degraded groundwater quality. BNL evaluates the potential impact of radiological and non-radiological levels of contamination by comparing analytical results to NYS and DOE reference levels.

The predominant groundwater flow direction in the Booster Applications Facility area is to the south-southeast. Until recently, groundwater flow directions in the Booster Applications Facility area were influenced by the operations of AGS cooling water supply wells 101, 102, and 103, which are located 1,200 to 2,000 feet to the west of the Booster Applications Facility. During periods of continuous use, pumpage totaling nearly 1,200 gpm resulted in a more southerly groundwater flow direction in the Booster Applications Facility area. However, in July 1998 the AGS supply wells were decommissioned, and the AGS's cooling water is now supplied by the BNL potable water system. It is now expected that the groundwater flow directions in the Booster Applications Facility area will be consistently to the south-southeast. The closest BNL potable water supply is supply well 10 located approximately 2,100 feet to the east of the Booster Applications Facility. Results from supply well capture zone modeling indicates

that under sustained pumping conditions, approximately 8 to 10 years would be required for groundwater to travel from the Booster Applications Facility to supply well 10.

The demography is such that about a third of the 1.37 million people that reside in Suffolk County live in Brookhaven Township where the Laboratory is situated. Approximately eight thousand people live within 0.3 miles of the Laboratory's boundaries.

Funding from the U.S. Department of Energy drives the demography of the BNL site. Brookhaven National Laboratory is a multi-program scientific center that develops and operates large-scale, state-of-the-art research facilities that are beyond the capability of any single university. In carrying out DOE's mission at the Laboratory, BNL's staff conducts its own basic and applied research at the frontiers of science through long-term programs in physics, chemistry, biology, medicine, energy and environmental sciences, and nonproliferation and national security. In addition, Brookhaven's 3,000 scientists, engineers and support staff collaborate and/or meet the needs of the more than 4,000 visiting researchers who come to the Laboratory each year from across the country and around the world.

Today, the Laboratory is home to four Nobel Prize-winning discoveries in physics. The first Nobel Prize for research developed at BNL was awarded in 1957, for a theory on parity conservation. The physics prizes in 1976, 1980 and 1988 were awarded for discoveries made using Brookhaven's Alternating Gradient Synchrotron (AGS). The AGS is one of the world's premiere particle accelerators and currently the only heavy-ion accelerator for radiation-biology research in the U.S. In addition, the AGS now also serves as a pre-accelerator for the Laboratory's Relativistic Heavy Ion Collider, which is the world's newest and biggest particle accelerator for nuclear physics research.

Since 1998, Brookhaven Science Associates (BSA), a nonprofit, limited-liability company established in 1997 by Battelle and the Research Foundation of the State University of New York (SUNY) for SUNY at Stony Brook, has operated BNL under contract with the U.S. Department of Energy. BSA's goal is to encourage internationally significant and nationally important science research to be done at Brookhaven, while ensuring the quality of the Long Island environment, the safety of the surrounding community, and the health of the Laboratory's staff and visitors.

Founded in 1977 as the 12th cabinet-level federal department, the U.S. Department of Energy oversees much of the scientific research in the U.S., through its support of BNL and the eight other national laboratories. Today, the U.S. Department of Energy not only provides the majority of Brookhaven's research dollars and direction, but also it is the government agency responsible for the Laboratory's operations and environmental stewardship.

The adjacent facilities that may affect the Booster Applications Facility are experimental operations in Building 919, and the operation of the Booster in Building 914. Both operations may contribute radiation exposure to occupants of the Booster Applications Facility. The design criteria adopted by Collider-Accelerator Department is that operation of these adjacent facilities be planned such that they contribute less than 25 mrem in one year to Booster Applications Facility occupants. Alternatively, it is not anticipated that radiation from Booster Applications Facility operations will affect occupants located at Building 930 or Building 919, which are the closest occupied non-BAF facilities.

### 3.2. Design Criteria and As-Built Characteristics

The Booster Applications Facility is essentially an extraction system in the Booster ring followed by a beam line, target area and beam stop, with adjacent experimental and utility support buildings. A packet of ions in the Booster ring, a beam pulse, is extracted into the Booster Applications Facility over periods up to 1 second in length. This pulse duration is termed “slow” extraction. The design criteria and as-built characteristics for the Booster Applications Facility; that is, the Slow Extracted Beam (SEB) system, the beam transport line, the safety systems, the Target Room and the Support Laboratories are as follows.

The Booster has operated since 1991 as a fast beam-injector of protons and heavy ions into the AGS. In order to deliver an external slow extracted beam to the Booster Applications Facility, new equipment was installed and some rearrangement of existing apparatus occurred. These changes are separately described in an Unreviewed Safety Issue ([Appendix 5](#)) associated with the Booster Safety Analysis Report.<sup>13</sup>

This new additional slow-extraction mode of operation is aimed at providing the most versatile experimental beam and range of energies and intensities practicable, as shown in Table 3.2. Intensities as low as  $10^3$  ions per pulse are available to experimenters by collimating the extracted beam with a single jaw collimator.

Table 3.2 Operating Parameters for Slow Extraction for some Typical Ion Species

Species	Charge State in Booster	Kinetic Energy Range, GeV/nucleon	Estimated Maximum Intensity, $10^9$ Ions per Pulse
p	1	0.73 to 3.07	100
28 Si	14	0.09 to 1.23	4
56 Fe	21	0.10 to 1.10	0.4
63 Cu	22	0.10 to 1.04	1
197 Au	32	0.04 to 0.30	2

The SEB system consists of a thin magnetic septum, thick magnetic septum and four lattice sextupoles. The extracted beam passes through a stripping foil before entering the Booster D6 septum magnet. The thickness of the foil is adjustable to completely strip the ions and allow for a uniform beam spot at the target area. The extraction efficiency is about 70 to 80%. Since the SEB beam intensity and energy for the Booster Applications Facility is low, the extraction efficiency value is acceptable from a radiation protection standpoint. That is, radiation from SEB extraction losses in the Booster is much less than radiation from routine loss of protons experienced during high-intensity running or during proton studies on the Booster dump.

<sup>13</sup> AGS Booster Final Safety Analysis Report, Editor: E. Lessard, Brookhaven National Laboratory, Upton, New York 11973, February 27, 1991.

The thin septum magnet is similar in design and specification to the F5 extraction septum used in the AGS but it is built to  $10^{-11}$  torr ultra-high vacuum standards. To meet this ultra-high vacuum requirement the individual internal steel and stainless steel components and the vacuum chamber were vacuum fired at 950 °C and assembled in a clean room. A thin 0.76 mm copper septum was used to minimize the beam loss during extraction. Inconel water lines were brazed to each edge of the septum to cool it. A remote positioning system was installed to optimize the septum's orientation for the various extracted beams.

The thick septum magnet is similar in concept to the present F6 extraction septum magnet used for the Booster. The magnet core and the water-cooled copper bus work are located outside of the vacuum. A special "Y" chamber is used with an Inconel chamber for the extracted beam that fits in the aperture of the magnet. The Booster circulating beam goes in a nickel-plated steel chamber that is welded to the Inconel chamber at the upstream end. The septum magnet must be on at full field throughout the 0.1 to 1.0 second extraction time. Because of this, heating of the septum conductor is significant even with water-cooling. The magnet is run DC to prevent the heating and cooling cycles from causing fatigue stress failures in the copper conductor or friction wear problems with the insulation. This magnet is built with four small conductor windings in the septum and the back leg. This design is used in the AGS F10 extraction septum magnet that operates DC with similar currents. To meet the ultra-high vacuum requirement the steel, stainless steel and Inconel components of the vacuum chamber were vacuum fired at 950 °C and assembled in a clean room. The entire assembly including the magnet core, copper conductor, and associated insulation is bake-able to 300 °C to meet the Booster vacuum bake-out requirements.

A stripping foil mechanism and a radial single jaw collimator are upstream of the thick septum magnet. This foil holder/changer is similar in design to the mechanism currently used for Booster H<sup>-</sup> injection. The mechanism was re-engineered to minimize the amount of space that it takes at the upstream end of the septum magnet. To aid with the setup of the extracted beam, it has a scintillation flag position with associated camera port, light port and camera mounting hardware in the tunnel.

Associated with the moved and new equipment installations in the Booster ring are modifications to the vacuum system. The major hardware pieces are new vacuum chambers, flanges, chamber modifications, bake-out blankets, wiring associated with the bake-out blankets, additional heater relay boxes, updated bake-out computer control software and tests of the system.

### 3.2.1. Design Criteria and the As-Built Characteristics for the Booster Applications Facility Instrument Systems

For efficient operation, the characteristics of the beam must be measured and displayed. The design criterion is that instrumentation for beam monitoring must be present in following four categories: beam position, beam profile, which is measuring the size and shape of the beam, beam intensity and beam loss.

The instrumentation for the Booster Applications Facility beam line must also include a number of different types of instruments to cover the full range of ion species and beam intensities. A list of the various instruments used can be found in Table 3.2.1, and a schematic view of their location in the beam line is shown in Figure 3.2.1.a. The

main elements guiding the tuning of the beam line are the 7 flags, which are phosphorus materials that measure beam profile, and the 5 segmented wire ionization chambers (SWICS), which are proportional chambers with a wire mesh that also measure beam profile. The flags will be viewed by cameras recessed into the tunnel shielding and the camera images will be processed by a frame grabber and image processor. Three ion chambers (IC) provide additional information about the integrated beam intensity along the beam line. Most of the instruments have to be retractable in order to be able to transport low-energy ion beam down to the target. For this same reason, there is no window separating the Booster vacuum ( $\sim 10^{-11}$  torr) from the Booster Applications Facility beam line vacuum. This requires the instrumentation to be mounted in ultra-high vacuum compatible boxes and be bake-able in the straight section upstream of the 20-degree bend.

Table 3.2.1 Booster Applications Facility Instrument List

Location Just Upstream Of:	Flag	SWIC Wire Spacing (32/plane)		Beam Size (90% full width)		Ion Chamber	Scint. /PMT
		Horizontal	Vertical	Horizontal	Vertical		
1) D6 Septum	Yes	N/A	N/A	25 mm	25 mm	No	No
2) Q1	Yes	6.5 mm	6.5 mm	60 mm	120 mm	No	Yes
3) D1	Yes	1.5 mm	5 mm	17 mm	75 mm	Yes	No
4) O1	Yes	6.5 mm	1.5 mm	90 mm	8 mm	Yes	No
5) O2	Yes	3 mm	6.5 mm	20 mm	90 mm	No	Yes
6) Final window	Yes	None	None	200 mm	160 mm	No	No
7) DS window	No	6.5 mm	6.5 mm	>200 mm	>160 mm	Yes	Yes
8) Target Area	Yes	N/A	N/A	>200 mm	>160 mm	No	No

The expected range of particle intensities covered by the various instruments is broad, from  $^{198}\text{Au}$  to  $^1\text{H}$ , from 0.04 to 3.07 GeV/n, and from  $2 \times 10^3$  to  $1 \times 10^{11}$  ions/pulse. Beam intensities that are  $10^3$  ions per spill or lower are under consideration by future Booster Applications Facility users. At these low intensities, it is not possible to see the beam profiles on the flags or SWIC's. The integrated intensity is monitored using plastic scintillators that can count individual ions. The low intensities are achieved by closing the collimator upstream of the D6 septum, a collimator with vertical jaws and scissor type motion, in combination with the use of a vertical stripping wire to define a small horizontal aperture. The instrumentation electronics and controls will be located in Service Building 957, see Figure 3.2.1.b, which also houses the beam line magnet power supplies.

Figure 3.2.1.a Booster Applications Facility Instrument Locations

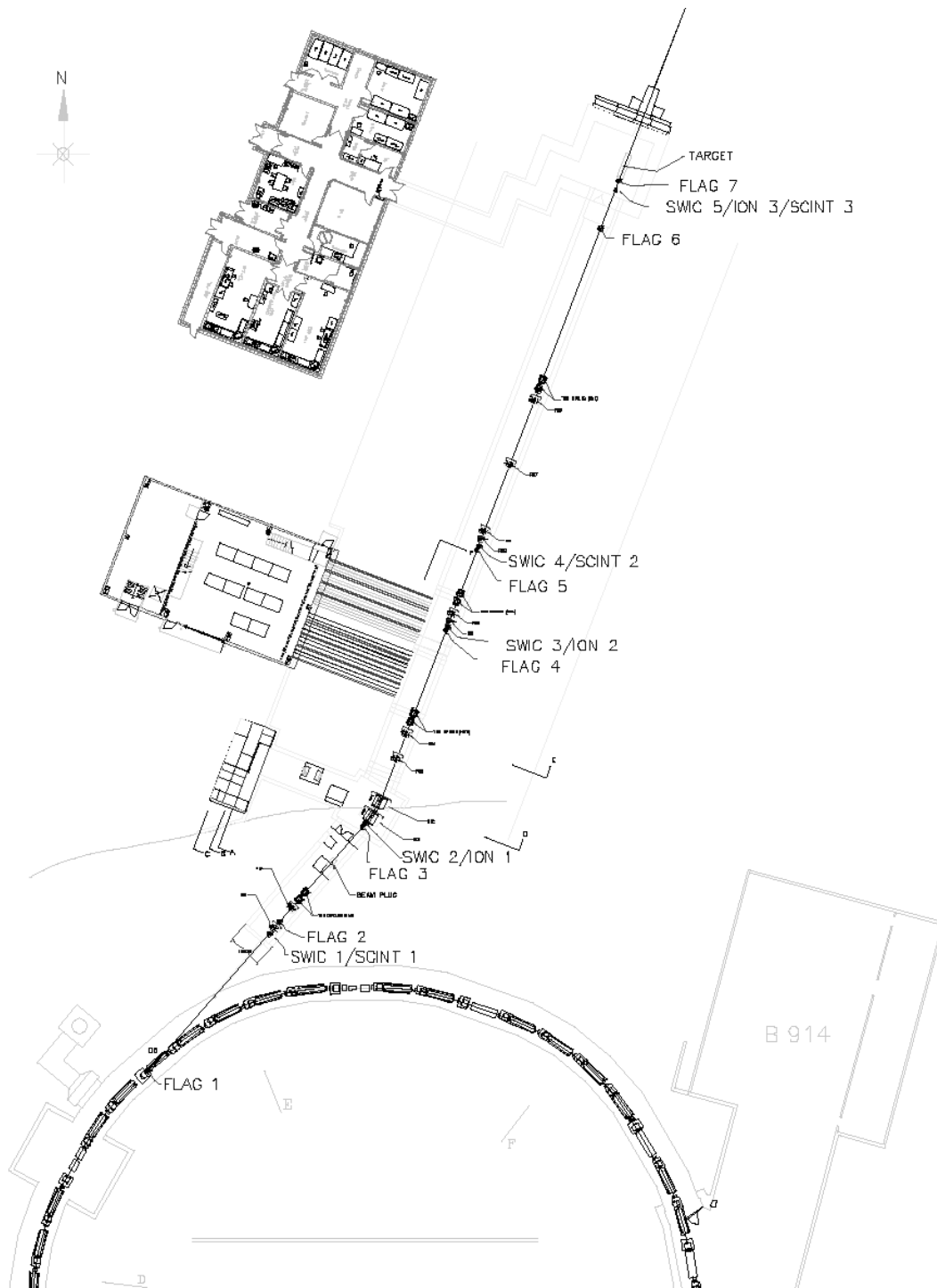
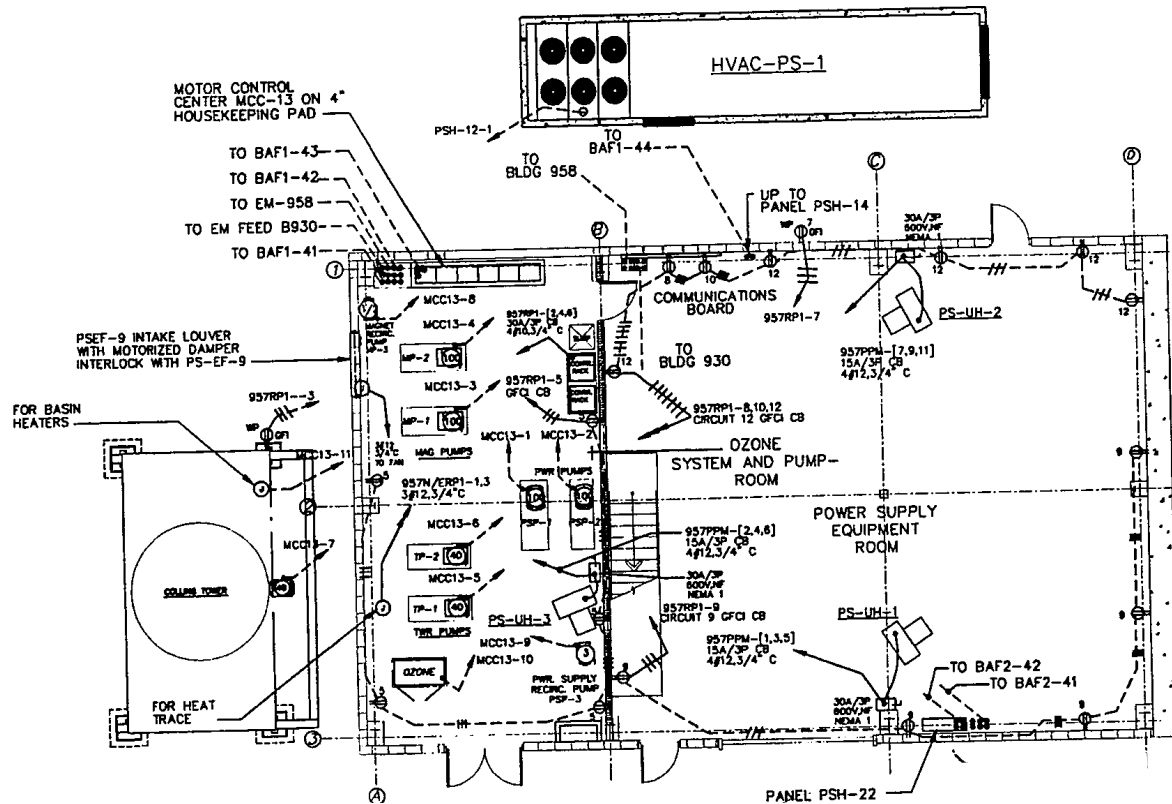


Figure 3.2.1.b Service Building 957



In order to monitor beam position, MCR operators use the plunging SWIC's and flags to measure beam profiles, using this data they calculate position in the transport line during setup periods.

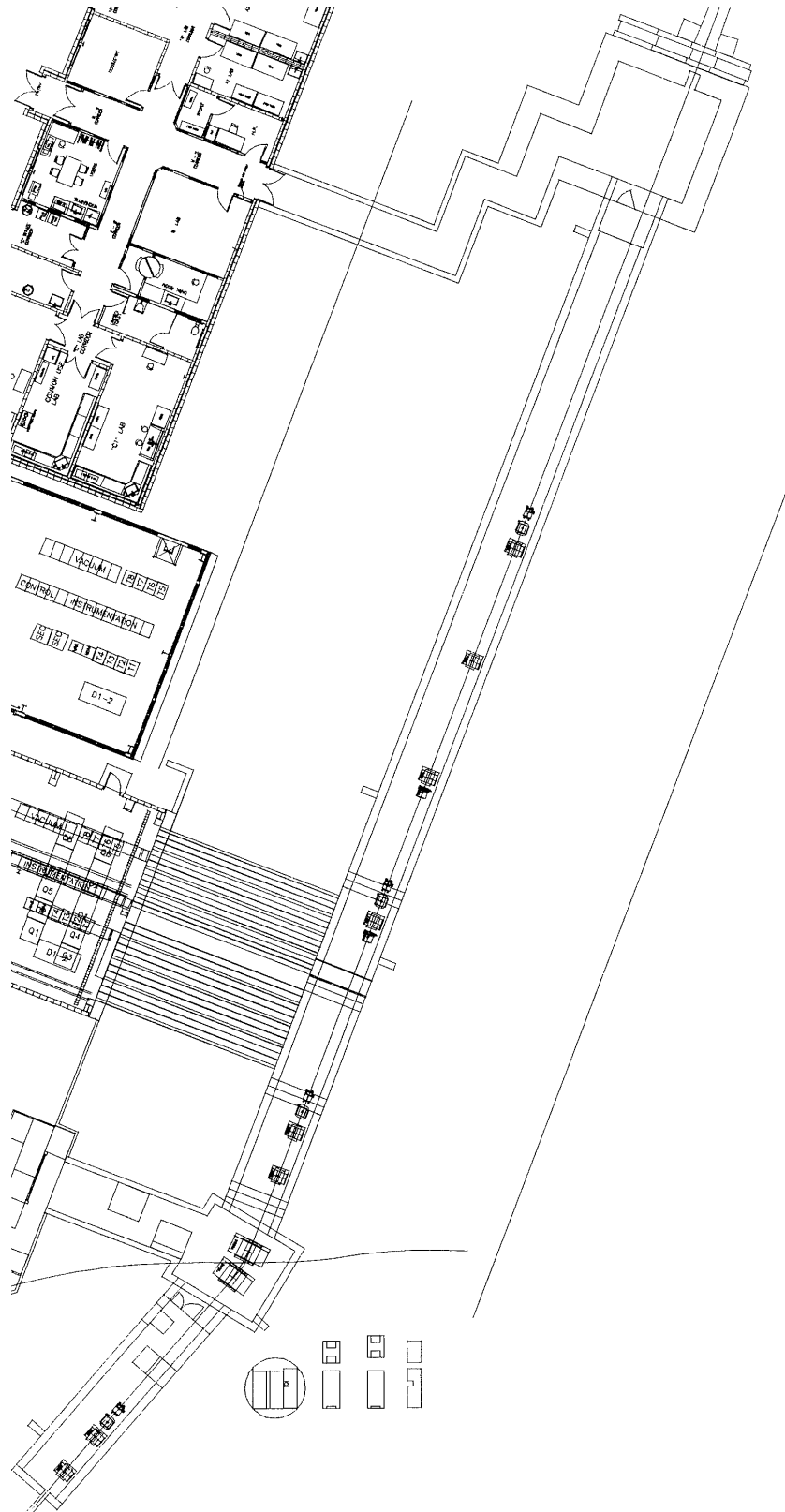
MCR operators rely on Booster ring diagnostics and data from the experimenter's dosimetry system to minimize unwarranted beam loss in the Booster and Booster Applications Facility. It is noted that the present beam-loss detectors and electronics installed in Booster are not sensitive enough to measure low-intensity, low-energy heavy-ion beam loss with accuracy. Since measurable activation from occasional low-intensity, low-energy heavy-ion beam loss is not expected, MCR operators rely on the experimental group to alert the control room if beam is not reaching the experimental area as anticipated. During setup and during runs, the NASA experimental group has on-line segmented ion chambers to monitor beam position, and ion chambers to monitor beam intensity. These devices are just downstream of the target area. Initially, MCR operators optimize the beam tune-up to experimenter specification, and then retract all MCR controlled instrumentation with the exception of the final non-plunging flag. Experimenters then confirm with their diagnostic equipment and dosimetry devices that the beam characteristics meets their needs.

### 3.2.2. Design Criteria and As-Built Characteristics for the Booster Applications Facility Magnets, Vacuum and Control Systems

The beam transport line delivers the extracted Booster beam from the extraction point of the Booster, to the target in the experimental area and provides the required beam profile on the target. The transport line starts at the beginning of the D6 straight section of the Booster, and ends at the target that is located 100 m downstream. The layout of the magnetic elements that transport and shape the beam on target is shown in Figure 3.2.2, and a brief list of these elements is given here.

- The thick septum magnet (not shown in Figure 3.2.2), placed just after the (D6) Booster extraction point, bending the beam by  $8.9^\circ$  (155 milliradians) to the left, thus extracting the beam from the Booster ring.
- Two dipoles, each 0.9 m long with 15 cm gap, each bending the beam by  $10^\circ$  for a total of  $20^\circ$  bend to the left to direct the beam into the final straight section of the tunnel. These dipoles are placed at a distance of  $\sim 33$  m from the beginning of the beam transport line.
- Eight magnetic quadrupoles all 60.9 cm long with 20 cm aperture. Two quads are placed upstream of the  $20^\circ$  bend and the six downstream of the  $20^\circ$  bend.
- Two magnetic octupoles 50 cm long and 20 cm aperture. Each of the octupoles is placed downstream of the  $20^\circ$  bend in order to provide beam shaping and uniformity at the target.
- Eight trim magnets (dipoles) are distributed throughout the beam line in order to keep the beam centered.

Figure 3.2.2 Booster Applications Facility Magnet Layout



Because it would cause unacceptable beam losses for low momentum heavy ion beams, a vacuum window cannot be used to separate the Booster  $10^{-11}$  torr ultra high vacuum system from the beam-line vacuum system. Instead, a transition vacuum from the Booster ring vacuum to the line vacuum is provided. Pressures of  $10^{-10}$  torr and  $10^{-9}$  torr are required in the first two vacuum sections of the line respectively. To accomplish this, all parts in the vacuum system are cleaned and assembled to ultra-high vacuum standards. The first section of the line is bake-able to 150 °C. The rest of the line is a clean all-metal gasket, unbaked vacuum system with ion pumps similar to the RHIC transfer-line vacuum system. Conflat<sup>R</sup> flanges are utilized throughout the beam line. Non-evaporative getters (NEG) that provide high pumping speeds are used with ion pumps in the first two sections. Ion pumps only are used for the balance of the line. Cold cathode gauges and Perani gauges are used for the entire line. Because of the bake-out/ultra-high vacuum requirements, all metal valves with metal sealing gates are used for the first two sectors. For the rest of the system, the valves have Viton<sup>R</sup> sealing gates that are significantly less expensive. A fast closing valve is installed to protect the Booster ring from a catastrophic vacuum failure in the line. The vacuum system includes the vacuum chambers that are installed in the beam-transport system magnets, the vacuum window at the downstream end, and a ceramic break at the upstream end. The vacuum system also includes special chambers for beam instrumentation equipment and the collimators. Bake-out blankets required for the upstream end of the line, wiring for the bake-out blankets, heater relay boxes, computer modules, and bake-out computer control software also are part of the vacuum system.

Controls include distributed controls, such as Ethernets or timing circuits that interconnect Tandem, Booster extraction and Booster Applications Facility beam-line equipment locations, and central controls, which are computers and software that control Booster rf and magnet power supplies that help provide beam for the Booster Applications Facility. Also included in this central class of controls is the hard-wired, non-computer, relay-based Access Control System that permits entrance to beam areas only when it is safe to do so. The overall design criteria and as-built characteristics for central controls are:

- Beam Spill Control - The desirable performance for the spill control system is a spill period of 0.1 to 1 second with low frequency ripple during the spill. A computer directs the system's major parameters and its output feeds the Booster main magnet power supply (MMPS) electronics. The major spill parameters that are controlled are the start and the duration or length of the spill. Other controls include beam allowed and beam inhibit modes of operation. An ion chamber near the start of the beam line serves as the detector for the spill control. In normal operation, the ion chamber is used to generate a correction signal, or the chamber is retracted and the system is run using a derived correction signal, which is stored.
- Spill Ripple Control - Spill ripple, or change in the intensity of the extracted beam during the 0.1 to 1 second spill period, is caused by fluctuations of the power supplies for magnets in the Booster ring and the extraction magnets. That is, a change in power to the magnets causes a change in magnetic field that in turn changes the intensity of the extracted beam.

If the beam is viewed as an apple skin and the extraction septum is viewed as a knife that peels the skin, then movement of the apple with respect to the knife will

produce a ripple in the peel. In the same way, movement in the radius of the circulating beam with respect to the extraction septum, movement that is due to a fluctuation in the magnetic field, produces a change in beam intensity during the spill period.

With the rf system on, a spill control servo is used to control this ripple in the extracted beam. That is, an ion chamber signal measuring beam intensity directs an rf control signal that directly influences the beam intensity. In this case, the spill control servo compares the intensity of the extracted beam with a reference signal and produces a control signal for the low-level rf system in the Booster. Since the rf system is used to change beam energy, the result is a virtually instantaneous change in the radius of the beam in the Booster. The beam intensity monitor is an ion chamber located near the end of the Booster Applications Facility beam line. The ion chamber is similar to the one used for Beam Spill Control. Using rf to counteract the changes in beam intensity due to fluctuations in power supplies for magnets is a rapid way to alter beam radius; that is, it is much more rapid than feedback to the power supplies, and the overall effect is to smooth out the ripple.

- Access Control System - An efficient and cost effective approach to the access controls implemented in the Booster Applications Facility was to augment the present Booster relay-based access controls system with a programmable-logic-controller (PLC) based system for this external area. Requirements for this system follow established Collider-Accelerator Department guidelines for limiting and controlling personnel access to beam enclosures, and for controlling possible prompt radiation concerns in adjacent areas.

### 3.2.3. Description and Design Criteria for Engineered Safety Systems

There are two engineered safety systems at the Booster Applications Facility and they are the fire detection/protection system and the access controls system for radiation safety.

The Access Control System for the Booster Applications Facility controls four gates that lead to the beam line or Target Room:

- Labyrinth entrance from the Support Laboratories (BGE1).
- Labyrinth entrance from the beam-line shield door (BGE2).
- Internal isolation gate at the upstream end near the Target Room (BGI1).
- Internal gate at the upstream end of the beam line (BGI2).

BGE1 and BGE2 are normal external access gates and are instrumented and interlocked to disable Booster Applications Facility extracted beam. BGE2 is designed to allow beam line access for large items; for example, a vacuum leak checking station. BGI1 allows unrestricted egress from the Booster Applications Facility tunnel into the Target Room but requires, in some access control configurations, a Controlled Access (CA) key and simultaneous release from the Main Control Room for movement from the Target Room to the Booster Applications Facility tunnel. BGI2 isolates the long straight section of the Booster Applications Facility tunnel from the beam line segment contiguous with the Booster penetration. A small shield-labyrinth is used in this region to mitigate the impact of beam loss in the Booster ring. BGI2 is instrumented and interlocked to the Booster injected beam for both the Linac and the Tandem.

Critical devices are beam-line elements that when placed in a safe state will eliminate the radiation hazard from the beam to safely permit access. As with other aspects of the access controls system, Collider-Accelerator Department requires two completely separate critical devices to be in force before allowing access to any area that can produce greater than 50 rem in one hour from beam. Each of these separate critical devices must mitigate the radiation hazard by itself. The D6 Septum, D3 Septum and D6 Extraction Bumps are the critical devices located in the Booster ring used to prevent beam extraction and allow access to the Booster Applications Facility beam line. See Figure 2, Appendix 5. The D3 septum itself is not efficient in preventing extraction. The D3 septum is combined with the bump power supplies as one critical device; the thick septum at D6 would be the other. Modeling shows that each of these two devices prevent primary beam from being extracted. There will still be the need to close the BAF beam plug for any access. It is noted that two critical devices are required and are considered adequate by the C-A Radiation Safety Committee to disable the extracted Booster Applications Facility beam. The Booster Applications Facility beam line magnets causing the 20° bend seen in Figure 3.2.2 are not used as a critical device since there is neither enough shielding nor another bend between these dipole magnets and the Target Room sufficient to mitigate the radiation hazard.

As opposed to disabling critical devices before an authorized entry, unauthorized access through BGE1, BGE2 and BGI1 gates or hitting a crash button causes the critical devices to be disabled, which excludes Booster extracted beam to the Booster Applications Facility. Access through BGI2 disables the Booster injected beam from both the Linac and TVDG.

Before permitting beam into any beam line, the MCR Operations group must ensure that the beam line enclosure is cleared of personnel. This is accomplished by a search of the area followed by an area reset. In order to make further entries and retain the swept state, the system is placed in the Controlled Access state. In the Controlled Access state, the entrants must obtain a key from the key tree. Under observation by MCR operators, entrants insert the key into the gate switch and receive a simultaneous gate release from the Main Control Room. Possession of the key by the entrant prevents a change from a safe state to the beam enabled state.

In order to limit the effort needed for clearing personnel from the affected area, the Booster Applications Facility beam enclosure is divided into three sweep zones. Each zone is instrumented with reset stations appropriately located to focus attention during the sweep in locations of limited line-of-sight.

There are two gate position-sense switches mounted at each gate. These switches give a positive indication that the gate is in the closed position. Each gate has one electric strike. In Controlled Access state, the electric strike must be energized from the MCR in order to access the area. All gates provide a means of emergency egress. The emergency-crash-glass on gates, which is used to permit emergency access to the area, is monitored and will interlock the beam if not intact.

The Restricted Access state applies to all Booster Applications Facility enclosure gates and does not require a key from the key tree for access. Entrants are issued a special key for access and beam is disabled by operations staff using the critical devices. On the other hand, Controlled Access entry requires a key from the key tree and a simultaneous gate release from MCR for access and egress. In this state, control and

tracking of those entering the area is done by an MCR Operator using video cameras. Trained entrants to the Target Room during a Controlled Access are identified by a bio-scanning unit, such as an iris scanner or palm reader that verifies the entrant's enrollment in the database. Enrollment can only be made by authorized C-A staff who verify completion of required training before enrollment of the user. The scanner is located near BGE1. A successful scan releases a key from the key tree.

It is noted that required training for Users is identified by performing a training assessment based on work planning documents and experiment reviews in accord with requirements in the SBMS Subject Area, Training and Qualifications. In similar facilities at the Collider-Accelerator Department, some level of radiological training is normally required in addition to facility specific training. This additional radiological training may address specific environmental, safety and health procedures, such as key-tree operation that are associated with a specific experimental area. In addition, the training assessment for Users identifies radiological training requirements that must be fulfilled in order to enter the experimental areas unescorted.

Other access-control-system devices include active radiation area monitors that reduce or eliminate unwarranted prompt radiation levels in occupied areas due to fault conditions. Active monitoring is provided in the upstream Booster Applications Facility beam line to monitor beam losses in the Booster Applications Facility extraction region of the Booster ring. The radiation area monitors used for this task are two (dual-redundant) interlocking Chipmunks. C-A Department will not use these chipmunks while BAF is running, but if there is to access the tunnel, or the Target Room, the two chipmunks in the upstream stub will be active, the same way they have been during construction. Three more chipmunks, active all the time, will also be used. Two are to be at the two external gates, the third one may be on the berm or behind the beam stop or in the power supply building near the penetrations for utilities. The final location, or the possible need for more, would be settled after review by the Radiation Safety Committee and results of initial fault studies.

These devices have a tissue equivalent response that measures radiation exposure in units of absorbed dose. The measured dose is electronically multiplied by a factor of 2.5 to indicate the dose equivalent. The factor's value was based on measurements of the energy of the neutron radiations found adjacent to AGS shielded facilities. The factor is used to adjust for the "quality" of the neutron radiation to cause stochastic effects relative to gamma radiation.<sup>14</sup>

Chipmunk radiation monitors interlock the Booster injected beam should significant Booster beam loss be noted in the extraction area. The interlock level is conservatively set at 2.5 mrem per hour and the alarm level set at 80% of the interlock level. The Radiation Safety Committee may change the interlock level to higher levels depending on need and ALARA considerations. Main Control Room operator response to alarms and interlocks is governed by formal reporting requirements set down in the Collider-Accelerator Operations Procedure Manual.

There are five basic design criteria for the Access Control System for the beam line:

- Either the beam is disabled or the related access control area is secured.

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<sup>14</sup> BNL Memorandum, Summary of Neutron and Gamma Measurements for FY96, Edward T. Lessard to Distribution, October 11, 1996.

- Only wires, switches, relays, programmable logic controllers and Collider-Accelerator Department Radiation Safety Committee approved active fail-safe devices are used in the critical circuits of the system.
- Where relays are used, the de-energized state of a relay is the fail-safe state; that is, the system is fail-safe.
- Redundant critical devices are used to disable the beam and redundant interlocks are used to secure the area.
- If a beam fails to be disabled as required by the state of its related access control area, then the upstream beam is disabled; that is, the access controls have backup or what is sometimes termed “reach-back.”

Brookhaven National Laboratory provides central fire-alarm station coverage by an Underwriter Laboratory listed multiplexed Site Fire Alarm System. The system complies with the requirements of NFPA 72 for a Style 7D System.

The system uses the existing site-telephone cable plant. RS232 signals are sent via full duplex line drivers. Each fire alarm panel has two channels connected to the Central Station. The panels are divided into 7 communication “loops.” The system can monitor more than 20,000 points. It is currently monitoring 3,800. Response time from alarm at the panel to alarm indication at the Central Station is less than 10 seconds, which is well within the 90 seconds allowed by NFPA 72.

The main console is at the Firehouse, Bldg. 599. This station monitors all fire alarm signals, trouble and communication status alarms. A satellite station at Safeguards and Security, Bldg. 50, receives only the fire alarm signals. If the Firehouse does not acknowledge an alarm within 90 seconds, the satellite station at Bldg. 50 will receive an audible indication to handle the alarm. A second satellite station at AGS Main Control Room, Bldg. 911, receives only the fire alarm signals from the RHIC/AGS accelerator buildings. A team of operators and Radiological Control Technicians respond during accelerator operating times.

Smoke removal ventilation is provided in the BAF tunnel. One 17,000 cfm exhaust fan is located at the tunnel’s mid point. Two make up air shafts are supplied by the exit points. Activation is by manual stations at the fire alarm control panel and the labyrinth entrance to the tunnel. While smoke-removal is not required by code, it is essential for fighting a fire in a windowless, underground facility.

The following is the basic design criteria for the fire detection/protection systems for the beam line:

- When provided, fire detection is spaced at a maximum of 400 sq. ft. per detector.
- Alarm devices are supervised for circuit trouble and ground fault conditions by the facility’s main fire alarm panel.
- Alarm and trouble signals report to the BNL Fire/Rescue Group via the Site Fire Alarm System.
- Wet pipe sprinkler systems are installed according to Factory Mutual Engineering Association hydraulic design criteria for ordinary industrial hazards.
- Water supply control valves to sprinkler systems are supervised by the Site Fire Alarm System.
- Manual fire alarm stations are provided at each exterior exit.
- Building occupants are alerted throughout the facility by combination fire alarm bells with integral strobe lights.

- Design criteria for response to fires follows the National Fire Protection Association's (NFPA) standards for installation and maintenance for fire detection systems (NFPA 72), fire sprinkler systems (NFPA 13), fire department standpipe systems (NFPA 14) and the National Electrical Code (NFPA 70). Additional refinement of the criterion is provided in BNL's ESH Standard on fire alarms.
- Only Underwriter's Laboratory (UL) approved or listed equipment is used, and it is used in the manner intended by the approval agency to ensure the most reliable functioning of the systems.

The basic design criteria for the Booster Applications Facility Target Room and support facilities fire detection/protection systems are:

- A wet pipe sprinkler system with control valve is installed according to Factory Mutual Engineering Association hydraulic design criteria for ordinary industrial hazards.
- Manual fire alarm stations are provided at each exterior exit.
- The fire alarm panel is located in the publicly accessible area.
- The ceiling and mezzanine-level smoke-detection will interrupt power-supply electrical feeds upon fire alarm.
- The ceiling level smoke detection will shutdown the heating, venting and air conditioning (HVAC) air-handling unit upon fire alarm in order to comply with the smoke control provisions of NFPA 90A, Chapter 4.

### 3.3. Design Features that Minimize Hazards and Prevent Pollution

The as-built characteristics that minimize the presence of hazardous environments and ensure chemical and radiation exposures are kept as low as reasonably achievable during operation, maintenance and facility modification are as follows:

#### Radiation Safety

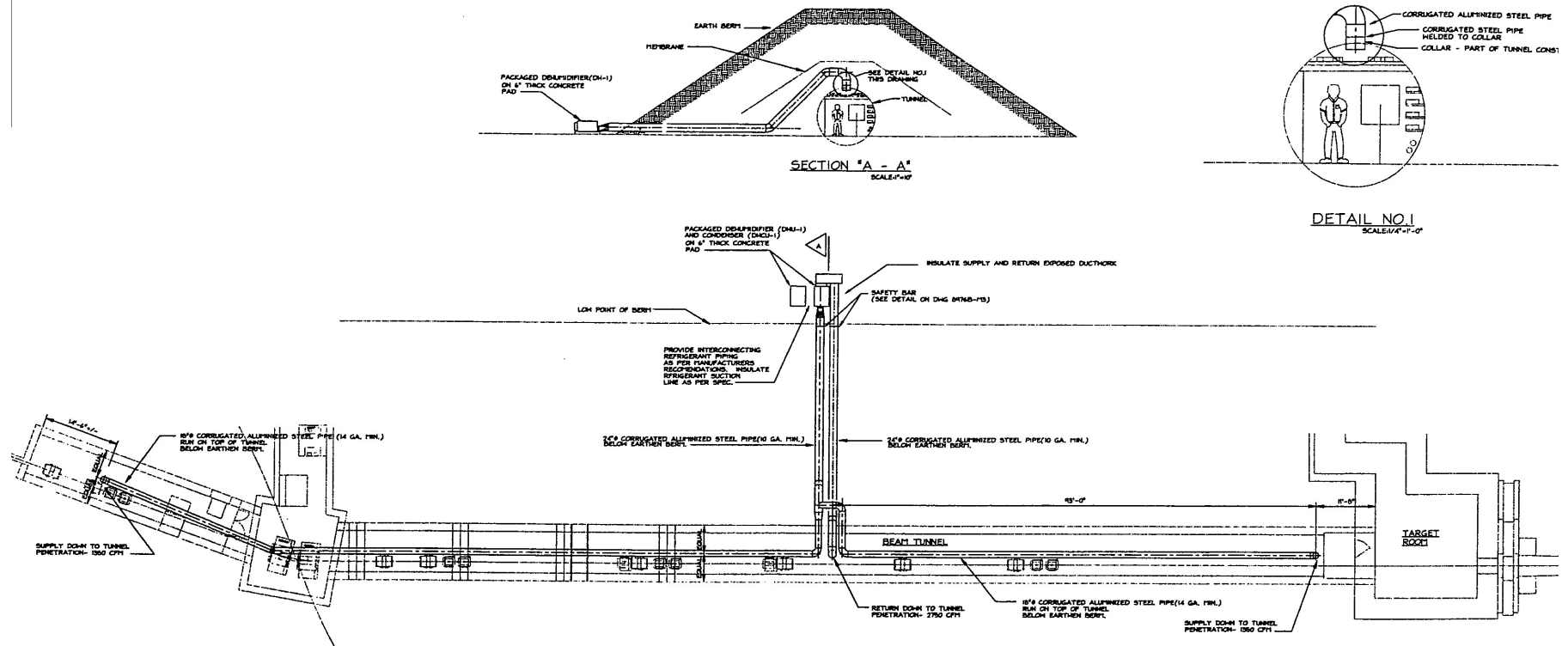
- Dual, fail-safe interlocks are used on gate entrances.
- Interlocked access-key-trees are used to capture gate access keys.
- An iris reader or a similar bio-identification system is used to release an access key to a trained individual.
- Crash cords are mounted inside the target cave and beam line.
- Interlocking area radiation monitors with pre-set trip levels are located throughout the Booster Applications Facility.
- Audible and visual warnings are issued before re-enabling the beam line and target cave to receive beam.
- The beam line and Target Room are fully enclosed to prevent access during operations.
- Fencing is used to limit access to other radiological areas.
- Shielding is thick enough to prevent exposure to primary beam.

#### Airborne Hazards

- Hoods and individual laboratory ventilation are used for radioactive tracer materials and hazardous materials in the Support Laboratories.

- Air and short-lived airborne radioactivity are re-circulated to allow for decay in the Booster Applications Facility beam line during operations. See Figure 3.3.a.
- Air emissions from the Target Room are vented to the outside. Airflow direction is from the Support Laboratories into the Target Room and out the exhaust point. See Figure 3.3.b.

Figure 3.3.a Air Re-Circulation in the BAF Tunnel



[illegible]

EXHAUST FAN SCHEDULE										
DESIGNATION	AREA SERVED	SERVICE	HP FLOW (CFM)		LOCATION	FAN TYPE	ELECTRICAL CHARACTERISTICS			MANUFACTURER & MODEL
			W/ FLOW	W/O FLOW			HP	W/ FLOW	W/O FLOW	
TY-EP-1	TARGET BAY	VENTILATION	W/ 0	0.00	TARGET BAY	CENTRIFUGAL	3/4 HP	480V	3/45/20/20	CARRIED VULC-BE-83
TY-EP-6	TUNNEL	PURGE	W/ 0	0.00	TUNNEL BAY	CENTRIFUGAL	1/2 HP	480V	480/24/12	CARRIED VULC-BE-77

### ALARA

- Soil is capped with a water-impermeable membrane to prevent soil activation from becoming a leachate that can reach groundwater.
- Multi-leg penetrations and labyrinths are used to minimize routine radiation levels.
- A re-entrant cavity and movable shield are used to minimize exposure to residual radiation in the Target Room from beam stop radioactivity.
- A sample translator or relay apparatus is used, when applicable, to minimize entrances to the Target Room.

### Electrical Safety


- There are no exposed conductors; all magnet buss work has covers.
- A sectionalizing gate divides the beam line and Target Room preventing inadvertent access to energized electrical devices.
- The National Electric Code is enforced for all facility electrical distribution systems.
- In-house-built electrical devices are reviewed for compliance with the National Electric Code by the Chief Electrical Engineer according to C-A OPM procedure.
- Fusing and other protective circuitry are used in experimental equipment in accord with C-A OPM procedures.
- Accountable key systems, such as captive key or Kirk Key where a key must be physically removed from one position and inserted in another lock to provide access, are used in accord with SBMS/BNL ESH Standard requirements.
- There are emergency-off controls for power.

### Life Safety and Fire Protection

- Manual fire alarm stations are located adjacent to all exterior exit doors from the beam line, Support Laboratories and Target Room.
- Fire detection, in the form of smoke detection, is located throughout the beam line.
- Fire alarms are provided.
- Fire sprinkler protection is located throughout the Support Laboratories and Target Room.
- Fire department hose standpipes are located at the entrances to the tunnel labyrinth and Support Laboratories.
- Wet pipe sprinkler systems are hydraulically designed for 0.15 gallons per minute per square foot over 2500 square feet of the most remote area with 250 gallons per minute for hose streams.
- Exits meet the requirements of the Life Safety Code.
- The use of flammable liquids will be minimal. The anticipated use is less than 1 quart in each laboratory space as a solvent. Any use of flammable liquids follows BNL ES&H Standards / SBMS requirements.
- Propane for Bunsen burners is either stored external to the Support Laboratory building or contained within a continuously vented cabinet, which discharges to the outside.
- Emergency lighting is provided in the windowless beam line.

- Fire extinguishers are provided throughout the complex with 75 feet as the maximum travel distance to an extinguisher.

#### Liquid Effluents

- A sump and sump alarm are located in the beam line to capture cooling water should it leak.
- All drain piping in the facility is connected to the BNL Sanitary Sewage System.
- ~~Floor drains in the animal rooms in the Support Laboratories have covers.~~ 
- All cooling water systems have water make-up alarms.
- There are no outdoor tritiated water piping or cooling systems.
- An isolated closed cooling-water system was used to reduce the volume of tritiated water.
- The domestic water supply is equipped with back-flow preventers to isolate the Booster Applications Facility domestic water supply systems.

### 3.4. Collider-Accelerator Department's Organization

The Collider-Accelerator Department is administered and organized to assure safe operation in accomplishing its mission. Its mission is to:

- Excel in environmental responsibility and safety in all department operations.
- Develop, improve and operate the suite of proton/heavy ion accelerators used to carry out the program of accelerator-based experiments at BNL.
- Support the experimental program including design, construction and operation of the beam transports to the experiments plus partial support of detector and research needs of the experiments.
- Design and construct new accelerator facilities in support of the BNL and national missions.

In meeting its mission, the Collider-Accelerator Department is under a formal [Conduct of Operations Agreement](#) with the Department of Energy.<sup>15</sup> The documentation used to comply with this agreement is the Collider-Accelerator Department [Operations Procedure Manual](#), Collider-Accelerator OPM,<sup>16</sup> which specifies key procedures, chain of command, authorized personnel and other operational aspects. The process used to assure that personnel are qualified in safe operations is an extensive training program, including formal examinations to certify operational qualifications where appropriate.

The Collider-Accelerator Department organization<sup>17</sup> is comprised of four Divisions, the Accelerator Division, the Experimental Support and Facilities (ES&F) Division, the Controls Division and the Environmental, Safety, Health and Quality (ESHQ) Division. It is the responsibility of the Accelerator Division to bring the Siemens motor generator or Westinghouse motor generator, TVDG, Linac, Booster, AGS and RHIC on line and to integrate the operation of these machines into that of the complete facility. The beams from the operation of these machines must be transported by operations through transfer lines; for example, TTB and AtR, and to experimental areas; for example, TVDG Target Rooms, Booster Applications Facility Target Room, Building 912 and Building 919 Target Rooms and at the RHIC intersecting

<sup>15</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/conductofops.htm> Conduct of Operations Agreement

<sup>16</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/procedures.htm> Operations Procedure Manual

<sup>17</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/OrgChart/OrgChart.pdf> C-A Organization Chart

regions. It is the responsibility of the ES&F Division to plan, design, build and maintain the primary and secondary experimental beam lines and provide technical support for instrumentation for experiments or accelerators. It is the responsibility of the Controls Division to provide software and hardware support for the accelerators. It is the responsibility of the ESHQ Division to provide environmental protection, safety and health related services to the staff and experimenters. The ESHQ Division provides technical work products, training services, referrals to outside professionals, documentation services, conventional and radiological safety services, environmental management and internal assessment resources to help resolve problems and meet requirements.

#### 3.4.1. Operations Organization Introduction

The RHIC, AGS, Booster, Linac and Tandem Van de Graaff operate through the Collider-Accelerator Department Main Control Room in Building 911. The Collider-Accelerator Department organization for operations is pictured in Figure 3.4.1. Responsibility for the safe and reliable operation of the Collider-Accelerator Department complex resides with the on-duty Operations Coordinator. The Operations Coordinator is the shift supervisor for the operating personnel and the focus for all operations related questions. The Collider-Accelerator Department complex is made up of a number of facilities that may include the TVDG, Linac, Booster, AGS, the Main Magnet Power Supply, rf acceleration system, injection equipment, extraction equipment, beam lines and the RHIC. Personnel that are responsible for the day-to-day operations of these facilities are members of the Accelerator Division, the ES&F Division, the ESHQ Division and the Controls Division. Additional personnel who support the operations are members of BNL's Radiological Controls Division, Environmental Services Division, Waste Management Division and Plant Engineering Division.

Depending on operations, personnel available to the Operations Coordinator during operations may include:

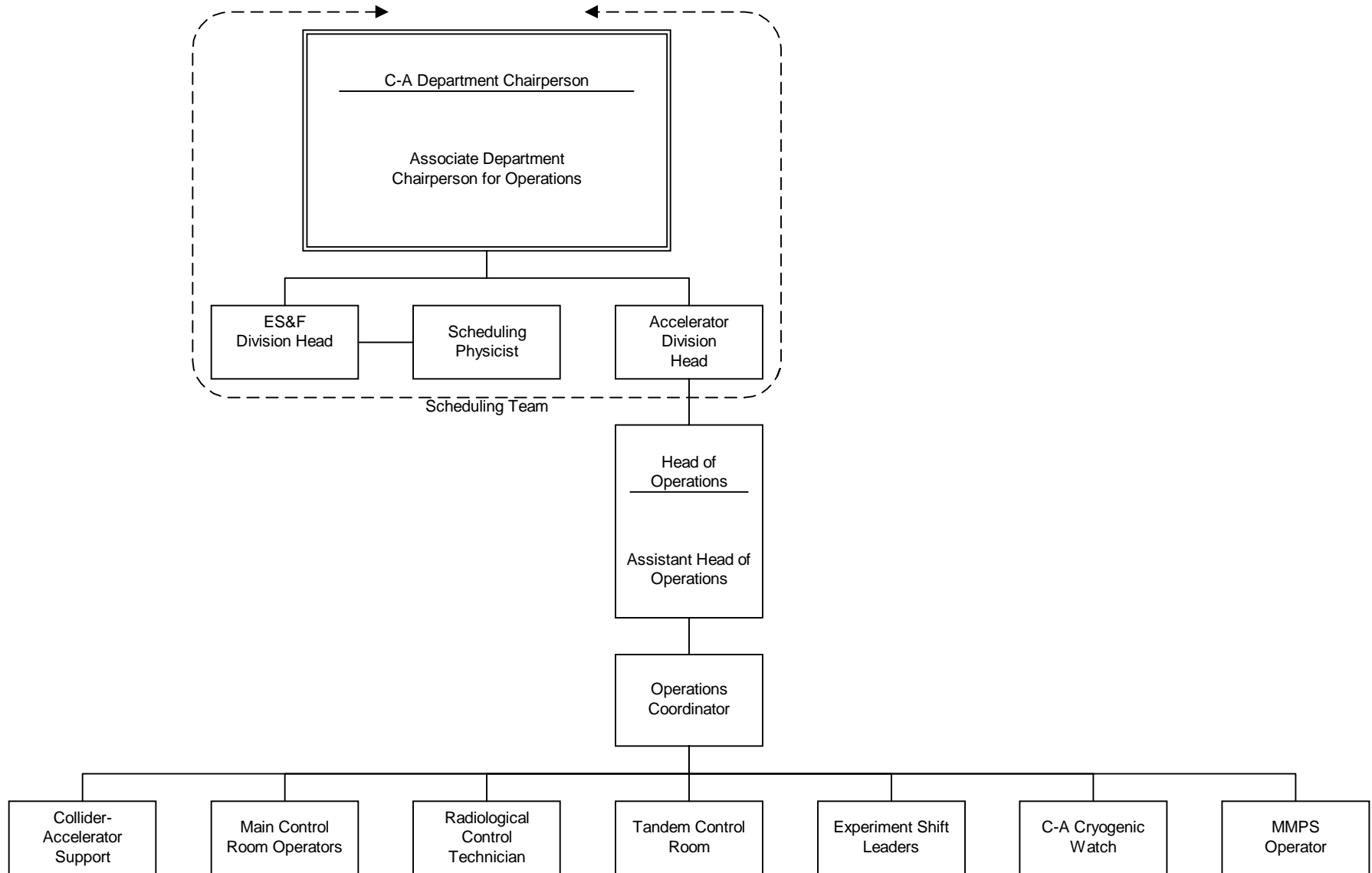
- The Main Control Room Operators.
- The Collider-Accelerator Support who are responsible for experimental area systems and beam line components.
- Power room operator who is responsible for the control of the Main Magnet Power Supply.
- Cryogenic Target Watch who are responsible for the operation of the liquid cryogenic targets, if any.
- Cryogenic Control Room Supervisor and Operators who are responsible to operate the refrigeration systems for cooling cryogenic magnets.
- Radiological Control Technician.
- Experiment Shift Leaders at the Collider.
- TVDG Control Room Operators.

Additional personnel available to the Operations Coordinator include the accelerator physicists and equipment systems specialists. Systems specialists repair equipment necessary for operations or provide trouble-shooting expertise when machine physics or equipment problems arise. Occasionally, it is necessary that parts of the accelerator complex be operated by accelerator physicists or systems specialists. The rules governing access to accelerator controls,

by such individuals, are found in the Collider-Accelerator OPM. In order to be allowed access to accelerator controls, accelerator physicists and systems specialists must:

- Recognize the role of the on-duty Operations Coordinator as the decision-maker regarding the safe and reliable operation of Collider-Accelerator facilities.
- Follow the orders of the Operations Coordinator, or his designate, during an emergency.
- Not operate any access-control-system consoles unless authorized to do so by the Access Controls Group Leader.
- Request permission to use the accelerator controls and state the purpose for the use of the controls to the on-duty Operations Coordinator.

Figure 3.4.1 C-A D Operations Organization



### 3.4.2. Operations Authority

Safe operation and maintenance of the Collider-Accelerator Department's science and technology (S&T) machines, injection systems, and experimental areas are under the supervision of the Collider-Accelerator Department Chair, the Accelerator Division Head, the Experimental Support & Facilities (ES&F) Division Head, the on-duty Operations Coordinator, and the supervisory structure. See the [Collider-Accelerator Organization Chart](#).<sup>18</sup>

Only authorized Department personnel operate the S&T machines. Direct daily supervision of shift operations is the responsibility of the on-duty Operations Coordinator. All Operators are authorized to shut down the S&T machines whenever an unsafe condition arises, or whenever they think that continued operation is not clearly safe. They are also authorized to take any other corrective safety- or environmental-protection-action as indicated in the Collider-Accelerator OPM. All scheduled operational-related maintenance is done with the authorization of the appropriate Work Coordinator, with the work-control authorizations prescribed in the Collider-Accelerator OPM and with the knowledge of the on-duty Operations Coordinator.

All operations have the appropriate authorization. Current holders of positions are denoted in the Collider-Accelerator Organization Chart. The following operations authorities are listed in the OPM:

- Department Chair Authorization
- Associate Chair Authorization
- Assistant Chair Authorization
- Division Head Authorization
- Group Leader Or Supervisor Authorization
- Authorization To Operate Systems
- S&T Machine Startup Or Restart Authorization
- Work Control Authorization
- Maintenance Coordinator Authorization
- Authorization To Classify, Remove Or Designate Approval For Procedures
- Department Chair, Division Head, Group Leader, Committee Chair And QA Authorization Of Procedures
- Committee Membership And Organization Chart Authorization
- Modification Of Training Authorization
- Authorization To Approve QA Level Classifications
- Authorization To Approve Purchase Requisitions and Intra-Laboratory Requisitions For ESHQ Compliance
- Authorization To Declare Systems As "Critical"
- Authorization To Approve Working Hot Permits & Procedures
- Authorization To Approve Lock & Tag Checklists
- Authorization To Approve Experiments
- Authorization To Approve New or Modified Accelerator Systems

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<sup>18</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/OrgChart/OrgChart.pdf> C-A Department Organization Chart

### 3.4.3. Administration and Organization Of ESHQ

The administration of ESHQ at Collider-Accelerator Department is via a hierarchy of documents: BNL Policies, BNL Standards of Performance, R2A2s, BNL Management Systems, BNL Subject Areas, Collider-Accelerator Department Conduct of Operations Agreement, Collider-Accelerator Department Facility Use Agreements, and at the working level, department procedures (QA Manual, Operations Procedures Manual, etc.).

BNL ESHQ Policies are the highest-level statements of BNL organization's philosophy for conducting business in a safe and environmentally sound manner. The number of policies is small. **Policies** are intended to form the complete set of foundational philosophies upon which the Laboratory operates.<sup>19</sup>

**Standards of Performance** are BNL "requirements" underlying Laboratory-wide procedures. Standards of Performance are intended to set performance expectations for BNL systems, managers and staff in accomplishing BNL Policies. By definition, the term "staff" includes all BNL staff and managers. Standards of performance also apply to those guests, visitors, and users who have a guest number and have been issued a DOE photo identification badge. Standards of Performance are high-level behaviors by which BNL carries out its policies, and are used to determine whether we are conducting our business and ourselves consistently with our mission, values and aspirations.<sup>20</sup>

The role, responsibility, accountability and authority statements (**R2A2s**) establish the expectations and duties of managers and staff for carrying out the work consistent with external and internal requirements.<sup>21</sup>

**Management Systems** are designed to translate the full set of external requirements into the information staff need to perform their work. Management systems are BNL's highest-level operating and business processes.<sup>22</sup>

**Subject Areas** are prepared when the requirements, procedures and guidelines apply to a broad group of staff across BNL.<sup>23</sup> If information only applies to a select or small group of staff, alternate methods of communications exist, such as task- or group-specific internal operating procedures. Subject Areas provide Laboratory-wide procedures and guidelines. They are developed to support the implementation of Standards. **Appendix 11** outlines the Collider-Accelerator Department strategy and schedule for meeting requirements pertinent to commissioning and operating the Booster Applications Facility, which are specified in the Accelerator Safety Subject Area.

In some cases, specific program description documents are used as the basis for operations by discrete groups of BNL staff that perform key activities to operate the processes and systems. In the case of the Collider-Accelerator Department, the basis for operations is defined in the **Conduct of Operations agreement**.<sup>24</sup>

A Facility Use Agreement (FUA) is also established for the Booster Applications Facility. The Collider-Accelerator Department Chairman, the Assistant Laboratory

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<sup>19</sup> <https://sbms.bnl.gov/policies/cl00d011.htm> BNL Policies

<sup>20</sup> <https://sbms.bnl.gov/perform/gstdd011.htm> BNL Standards of Performance

<sup>21</sup> <https://sbms.bnl.gov/standard/0x/0x00t011.htm> Roles, Responsibilities, Accountabilities and Authorities

<sup>22</sup> <https://sbms.bnl.gov/mgtsys/ms00t011.htm> Management System Descriptions

<sup>23</sup> <https://sbms.bnl.gov/standard/0000t011.htm> Subject Areas

<sup>24</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/conductofops.htm> Conduct of Operations Agreement

Director for Facilities and Operations, and the Deputy Director of Operations are the agreement parties for the FUA. The FUA clearly documents the respective roles, responsibilities and authorities for the Collider-Accelerator Department Chair and the Assistant Laboratory Director for Facilities and Operations for all aspects of facility operations. The DOE approved safety/authorization basis document for Booster Applications Facility, which is the Accelerator Safety Envelope (ASE), is a referenced attachment to the FUA. [Facility Use Agreements](#) (FUAs) define the operating boundaries/requirements including roles and responsibilities for the Booster Applications Facility.<sup>25</sup>

Internal operating procedures include task- or group-specific procedures that are used to implement management system processes. Collider-Accelerator Department procedures typically affect only the Collider-Accelerator Department facilities, which in this specific case is the Booster Applications Facility. The Collider-Accelerator ESHQ Division ensures that [Operations Procedures](#) are current and that they are based on and are not in conflict with the Laboratory-level governing documents.<sup>26</sup>

Each individual at the Collider-Accelerator Department is responsible for knowing and observing the rules. If any trained personnel observe any potential hazards, environmental problems or safety problems, then they must stop the work or activity and report it. Supervisors are responsible for all activities conducted within their facilities. Collider-Accelerator Department managers are committed to providing a safe and healthy working environment for all staff; protecting the general public and the environment from unacceptable environmental, safety and health risks; operating in a manner that protects the environment by applying pollution prevention techniques to current activities; and remediation of environmental impacts of past operations.

All Collider-Accelerator personnel are knowledgeable in applicable procedures located in the Collider-Accelerator Operations Procedures Manual (OPM). The OPM is designed to be a controlled document and to conform to quality assurance requirements set down in the Collider-Accelerator [Quality Assurance Procedures](#).<sup>27</sup>

The Collider-Accelerator Department ESHQ organizations are indicated in Figure 3.4.3. Several key ESHQ organizations and programs are described as follows:

The Associate Chair for ESHQ is a member of the Collider-Accelerator Department Chair's Office. The Associate Chair's functions are to implement new or revised environmental, safety, health training and quality programs, to carry out the leadership role for ESHQ, to inform personnel on the status of ESHQ, to establish communications and to maintain existing ESHQ programs. The overall approach is to integrate ESHQ into all work via formal Collider-Accelerator programs and procedures designed to ensure BNL's management systems are executed. BNL's management systems, which are located in the [Standards Based Management System](#),<sup>28</sup> are in turn designed to ensure that contractual requirements set by DOE are met.

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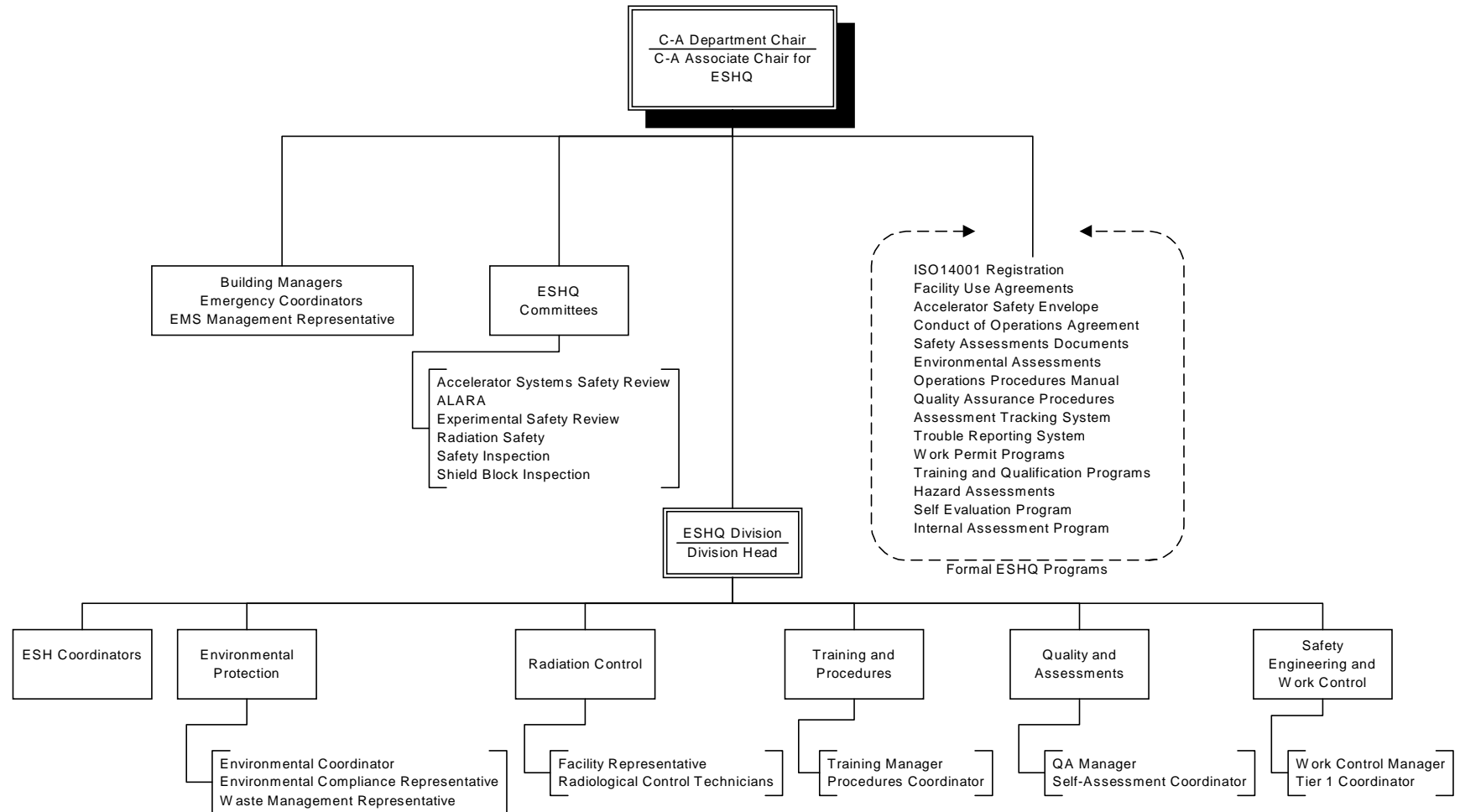
<sup>25</sup> <https://sbms.bnl.gov/private/fua/fa00t011.htm> Facility Use Agreements

<sup>26</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/procedures.htm> C-A Department Procedures

<sup>27</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/procedures.htm> C-A Quality Assurance Procedures

<sup>28</sup> <https://sbms.bnl.gov/ch00d011.htm>, BNL's Standards Based Management System

Figure 3.4.3 Representative Organization and Formal Programs for ESHQ at C-AD



For DOE, “safety” encompasses environmental protection, safety and health, including pollution prevention and waste minimization. DOE has identified five Core Functions to manage “safety.” They are:

- Define the scope of work.
- Identify and analyze hazards.
- Develop and implement hazard controls.
- Perform work within authorization agreement.
- Feedback and improvement.

DOE has identified seven Guiding Principles for performing the five Core Functions. The first three Principles apply to all Core Functions, the others to specific Functions given in parentheses:

- Line managers clearly responsible for ESH (all Core Functions).
- Clear ESH roles and responsibilities (all Core Functions).
- Competence commensurate with responsibilities (all Core Functions).
- Balanced priorities (define work).
- Identify ESH standards & requirements (define work, identify hazards, develop controls).
- Hazard controls tailored to work (develop controls).
- Operations authorization (perform work).

The management system that includes the five Core Functions and seven Guiding Principles has been named the Integrated Safety Management (ISM) by DOE. BNL’s management systems to implement ISM are located in the Standards Based Management System (SBMS). SBMS is on-line with Hypertext links to all referenced documents. The SBMS satisfies the contractual requirement for ISM. SBMS includes the following principle ESH programs and management systems:

- BNL’s Integrated Assessment Program.
- Laboratory level work-definition documents such as Subject Areas and BNL ESH Standards.
- Facility Use Agreements (FUA’s).
- Role, Responsibility, Authority and Accountability documents (R2A2s) and performance goals.
- Brookhaven Training Management System (BTMS).

At the Department level, BNL ESH Standard 1.3.5, Planning and Control of Experiments, is used by the Collider-Accelerator staff to guide experiments in order to:

- Determine the concept and scope of the experiment; assess for special requirements, review hazards and safety concerns.
- Develop an experimental plan and identify controls.
- Set up an experiment and obtain Experimental Safety Review Committee concurrence.
- Approve start-up and perform the experiment according to plan.
- Determine ways to improve next time.

In order to guide operations and maintenance of the accelerators, beam lines and associated systems at the Department level, BNL ESH Standard 1.3.6, Work Planning and Control for Operations, is used to:

- Define the scope of work in a Work Permit or establish the applicability.

- Identify the hazards via the Work Permit process and perform a pre-job walk down.
- Use the Work Permit processes to establish hazard controls and required training.
- Provide the pre-job briefing and perform the work according to plan/permit.
- Use the Work Permit feedback process to identify ways to improve next time.

The Collider-Accelerator Department uses committees and ESH staff to define the scope of the experiment or work, identify and analyze hazards and develop hazard controls. The ALARA Committee, Experimental Safety Review Committee, Accelerator System Safety Review Committee and Radiation Safety Committee meet requirements established in BNL ESH Standards 1.3.5 and 1.3.6. These Committees are composed of members of the Collider-Accelerator Department, other BNL scientific Departments, and members of the BNL ESHQ Directorate. These Committees operate under a system of formal procedures in the Collider-Accelerator OPM.

Self-assessment and self-evaluation are carried out by individual Department employees and by Collider-Accelerator's Safety Inspection Committee, Shield Block Inspection Committee and Quality Group. Formal procedures for conducting self-assessment and self-evaluations are listed in the Collider-Accelerator OPM. Formal tracking is via the [Assessment Tracking System](#) (ATS).<sup>29</sup>

### 3.5. Engineered and Administrative Controls Summary

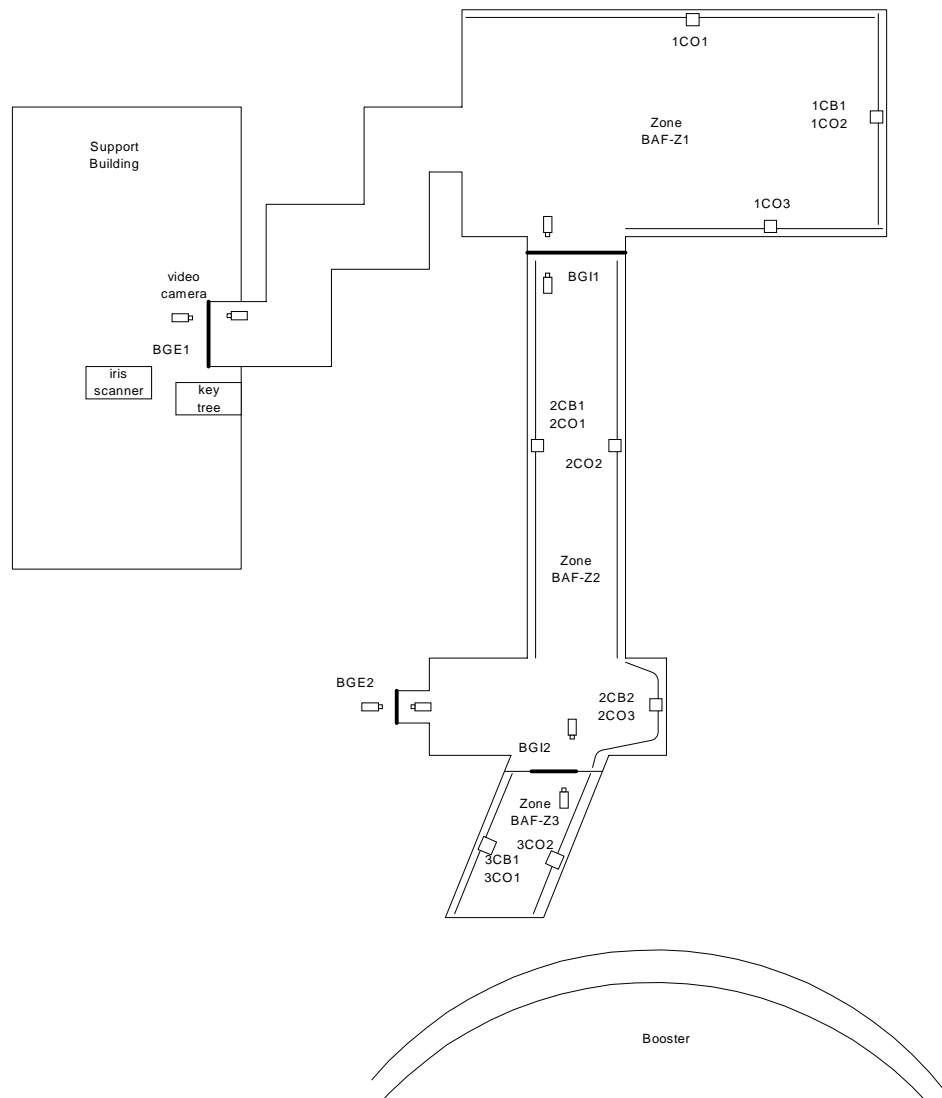
The engineered controls for routine operation and emergency conditions are:

- Access Controls System - The purpose of this safety significant system is to prevent inadvertent exposure to particle beams and to the secondary radiations produced from the nuclear cascades following high-energy particle beam interactions. The Collider-Accelerator Department Radiation Safety Committee (RSC) has defined the classification of the Booster Applications Facility Access Control System and its application. The RSC delineated the access, enclosure and minimum access-control requirements for each category of radiation area at Booster Applications Facility, and accounted for the potential levels of radiation during normal operations and the potential radiation levels during fault or during abnormal conditions. Wiring diagrams and functional tests are approved by the RSC. All Access Control System wiring and testing is performed and documented by qualified technicians and engineers in the Collider-Accelerator Access Controls Group. Changes to the system are controlled according to requirements in the BNL SBMS, Collider-Accelerator Department Quality Assurance Procedures and the Collider-Accelerator Operations Procedure Manual. The basic layout of the Access Control System for Booster Applications Facility is depicted in Figure 3.5.a. The Access Control System is a QA1 system, and all drawings and components are configuration controlled.

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<sup>29</sup> <http://ats.bnl.gov/> Assessment Tracking System

Figure 3.5.a Layout of Access Control System. Figure shows gates (BG#), video cameras, bio-scanning device, key tree, crash buttons (CB#), interlock zones (Booster Applications Facility-Z#) and crash operator-testing points (CO#)



- **Fire Protection System** - The purpose of this safety significant system is to mitigate fire damage and alert personnel to an imminent danger. The BNL Fire Protection Engineer prescribed the fire protection requirements for the Booster Applications Facility. The layout of the smoke detectors, sprinklers and purge exhaust fan for smoke is shown in Figures 3.5.b, 3.5.c, 3.5.d and 3.5.e. The system was acceptance tested by the Plant Engineering Division. System maintenance and testing is performed by qualified Fire Alarm Technicians in the Plant Engineering Division. Changes to the system are controlled according to requirements in the BNL SBMS and the Plant Engineering Division's Fire Alarm Inspection and Testing Procedures.



Figure 3.5.c Smoke Detectors and Fire Alarms in the Support Laboratories

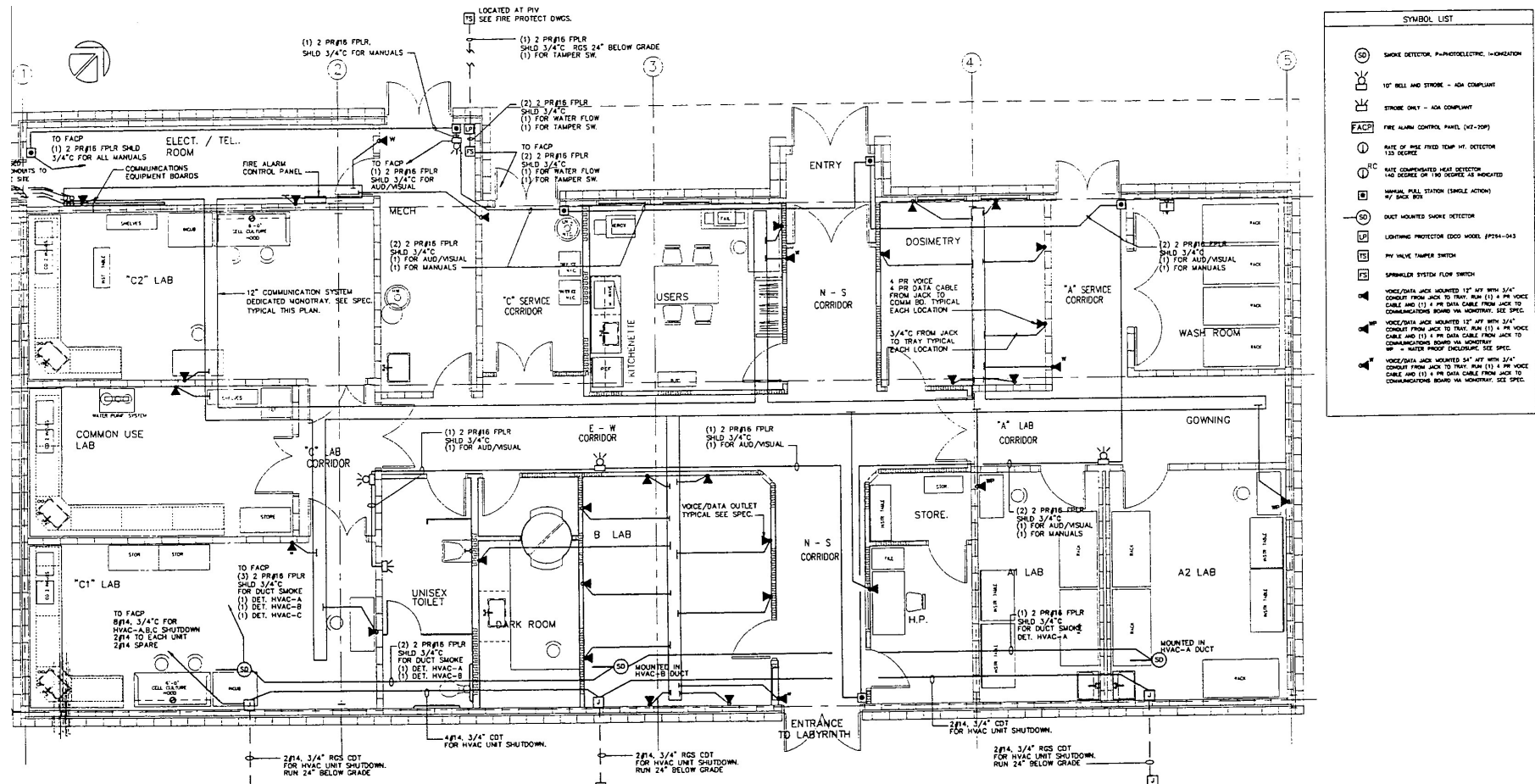
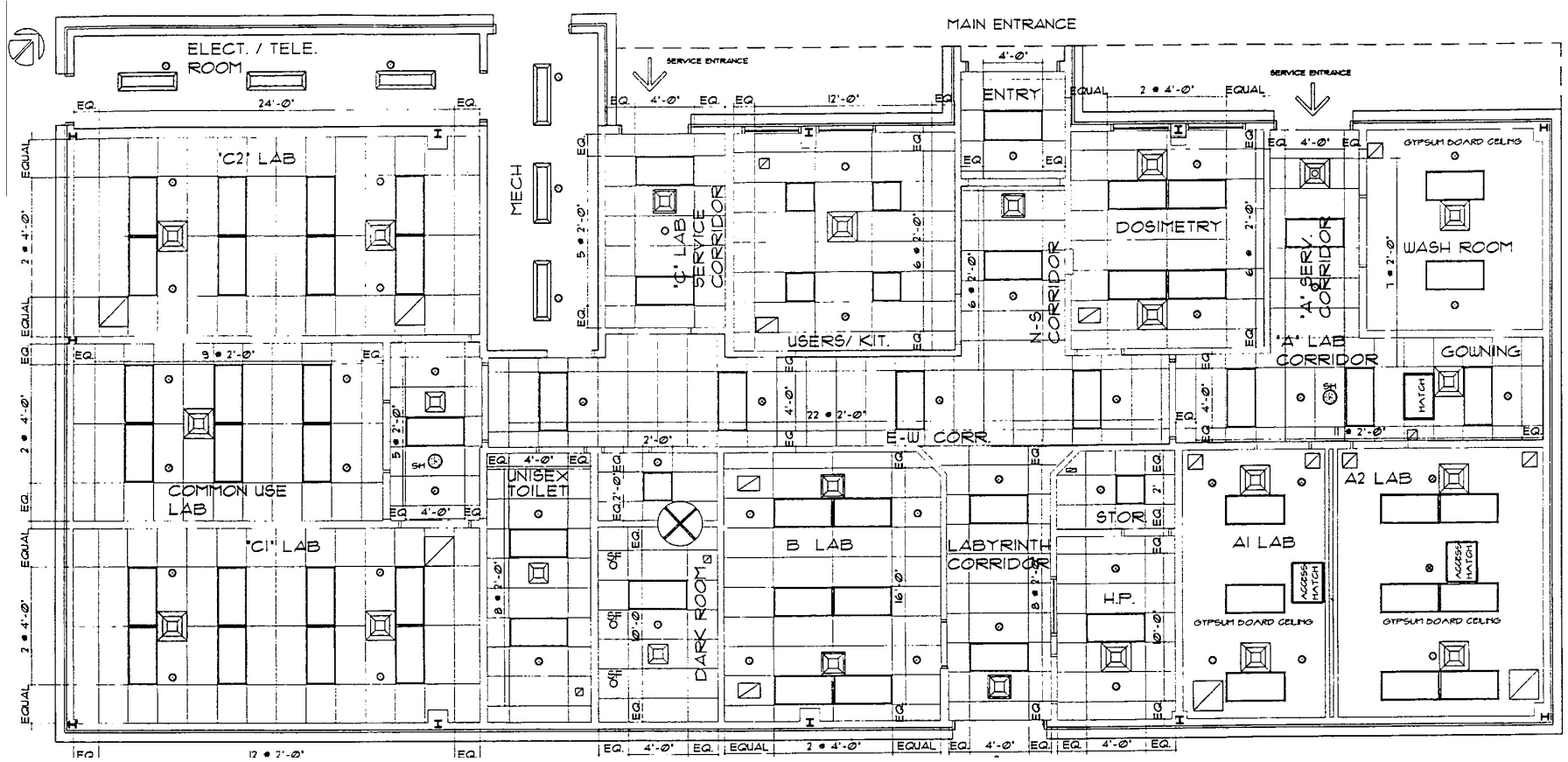


Figure 3.5.d Sprinklers in Support Laboratories



**TUNNEL FLOOR PLAN PURGE VENTILATION SYSTEM**  
SCALE: 1/4"=1'-0"

**SECTION "B-B"**  
SCALE: 1/4"=1'-0"

**SAFETY BAR DETAIL**  
SCALE: 1/2"=1'-0"

- **Beam Monitoring Systems** – The purpose of these machine protection systems is to minimize beam loss and to help provide the required beam on target. The Collider-Accelerator Department management has required that inadvertent beam loss occur at levels that are as low as reasonably achievable with operational, economic and community factors taken into account. As a minimum, the Collider-Accelerator Department has assigned the following responsibilities to the Accelerator Division Head or his designate:
  - Determine acceleration, extraction and transport loss limits for setting threshold values to activate alarms.
  - Formally, approve changes to acceleration, extraction and transport loss limits as operations evolve.
  - Determine appropriate instrumentation for measurement of the losses, and for ensuring measurements are reviewed at appropriate intervals in order to validate loss assumptions.
  - Ensure alarm threshold values used by operations personnel are incorporated into the appropriate computerized controls programs.
  - Ensure that operations procedures contain loss limits.
  - Ensure response by operators to alarms is clearly written in procedures. Loss problems must be corrected within minutes; otherwise, operators must reduce the beam intensity to the affected area.
  - Ensure authorization for any prolonged high-loss operation, with an alarm present, comes from the Collider-Accelerator Department Chair and is documented.
  - Ensure that the responsibility for maintaining loss-monitor systems is assigned.
  - Ensure beam current transformers and loss monitors used to determine operating efficiencies and losses undergo verification by the operations staff in the control room at start-up of a running period.
  - Ensure residual radiation surveys on the Booster Applications Facility beam line are made after the first operational running period in order to confirm loss assumptions.
- **Activated-Soil Caps** – The purpose of this engineered environmental control is to prevent rainwater from seeping through activated soil-shields. The Collider-Accelerator Department ensures leachate from activated soil due to rainwater or storm water is prevented by a cap that has been applied to activated soil at Booster Applications Facility to eliminate exposure to rainwater. The cap is designed to incorporate the following criteria, which is a design practice given in the [SBMS Subject Area for Accelerator Safety](#):
  - The peak rainwater infiltration rate is less than or equal to the infiltration rate in 45 cm of low-permeability soil with hydraulic conductivity less than  $1 \times 10^{-5}$  cm/sec with 2.54 cm of ponded water above the cap. This equates to an allowable peak infiltration rate of approximately 1.0 cm/day. This is approximately 0.3% of the infiltration rate for natural soils at BNL.
  - The long-term average infiltration rate is less than 0.12 cm/year. This is approximately 0.2% of the natural groundwater recharge rate at BNL.

The requirements for calibration, testing, maintenance, accuracy or inspections for the engineered safety systems necessary to ensure the operational integrity of the BAF Safety Envelope are:

- The Access Control System is functionally tested in accordance with requirements in the requirements in the [BNL Radiation Control Manual](#).
- Target Room and Support Building ventilation exhaust fans are to undergo annual testing not to exceed 15 months.
- BAF fire protection is to undergo annual testing not to exceed 15 months.
- Area radiation monitors are to undergo annual testing not to exceed 15 months.
- Radiological barriers are to undergo annual visual inspection not to exceed 15 months.
- Rainwater barriers for activated soil are to undergo annual visual inspection not to exceed 15 months.

The administrative controls for routine operation and emergency conditions are:

- Fire Hazards - Combustible material usage will be kept to a minimum level, as dictated by the instrument and equipment needs. Substitution of non-combustible materials will be done wherever feasible. Flammable materials cabinets are provided as required. The Experimental Safety Review Committee will review all combustible experimental materials. Fire hazards for the facility are addressed in detail in the Booster Applications Facility Fire Hazard Analysis Document, [Appendix 8](#).
- Magnetic Fields - Magnets are used in the beam line. Any significant magnetic fields produced by these magnets are contained within beam line enclosures or limited access areas. Areas where the magnetic fields are greater than 0.5 mT (5 Gauss) are posted with warning signs for personnel with pacemakers or other medical implants. Medical evaluation and training of personnel with such devices is required before entry into the areas. Training and evaluation of work practices is required for all personnel expected to be exposed to magnetic field strength greater than 60 mT (600 Gauss). Training includes the possibility of injury due to magnetic forces on objects.
- Electrical Safeguards - Electrical safety implementation is covered by Collider-Accelerator Department Operations Procedure Manual. Lockout/Tagout (LO/TO) procedures are followed for areas where electrical hazards are present. Workers who perform work on electrical systems will have LO/TO training as specified by BNL. If it is necessary to work on any equipment while it is energized, a Working Hot Permit will be issued.
- Protective Clothing - Any use of chemicals, hazardous materials or cryogenics will require review for personnel protective equipment. The clothing for a particular application is selected considering the expected hazards; a variety of clothing will likely be needed to meet all hazards. Heat stress is considered in specifying protective clothing requirements.
- Material Handling - All material handling at Booster Applications Facility will be conducted in accordance with procedures in the Collider-Accelerator Department Operations Procedure Manual, and the DOE Hoisting and Rigging Manual. Positioning of equipment may require the use of forklifts, overhead cranes and specialized lifting equipment. All personnel operating such equipment will be trained by the BNL Training Group. All material handling equipment will be inspected by appropriate BNL personnel.

- Elevated Work - Any work required at levels more than four feet above ground level will undergo Work Planning and fall protection evaluation.
- Emergency Procedures - Emergency response is governed by procedures in the Collider-Accelerator Department Operations Procedure Manual. The emergency plan covers possible hazards, emergency signals and expected responses. Each building at the Collider-Accelerator Department complex has signs posted indicating the emergency assembly areas, and the name and number of the Local Emergency Coordinator. The Local Emergency Coordinator is familiar with the hazards in the building, the utility locations and shut-offs, and any spill response supplies available. The Local Emergency Coordinator assists the Fire Rescue Group Incident Commander in responding to any incidents at the facility. The Booster Applications Facility has a separate emergency procedure in Section 3 of the Operations Procedure Manual in order to document area-specific emergency information.
- Radiation Protection – The radiation protection program at Collider-Accelerator Department is in accord with the [BNL Radiological Control Manual](https://sbms.bnl.gov/program/pd01/pd01t011.htm)<sup>30</sup>, which in turn complies with Title 10 Code of Federal Regulations Part 835, Occupational Radiation Protection. The Collider-Accelerator Department's Operations Procedures Manual includes task- or committee-specific radiological procedures that are used to implement the BNL radiological control system.

### 3.6. Critical Operations Procedures

Specific operations procedures that prevent or mitigate accidents are related to resetting the Access Control System to enable beam. These procedures involve clearing (sweeping) personnel from beam lines before enabling the beam line for potential operations. These procedures are found in Chapter 4 of the Collider-Accelerator Operations Procedure Manual. The basic principles behind the authorization and use of these procedures are:

- Wording must be consistent throughout the entire set of sweep procedures for the Collider-Accelerator Department; that is, specific terms must mean the same regardless of the location of the area being cleared of personnel.
- Before resetting for beam, it must be clear to the operator which sweep procedure from the set of sweep procedures applies under every access condition encountered in the field. If not, then the area is not reset for beam.
- Checklists are checked-off by the operations staff performing the sweep at the completion of each sequential step in the procedure.
- Annual re-training of operations personnel in access control procedures must be performed.
- New or modified sweep procedures must receive an independent review by the maintenance staff or their representative; these are staff normally cleared (swept) from the area.
- If the Operations Coordinator assigns a gate watch to record access and egress, then the gate watch task is solely to count personnel into and out of the interlocked area.

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<sup>30</sup> <https://sbms.bnl.gov/program/pd01/pd01t011.htm> BNL Radiological Control Manual.

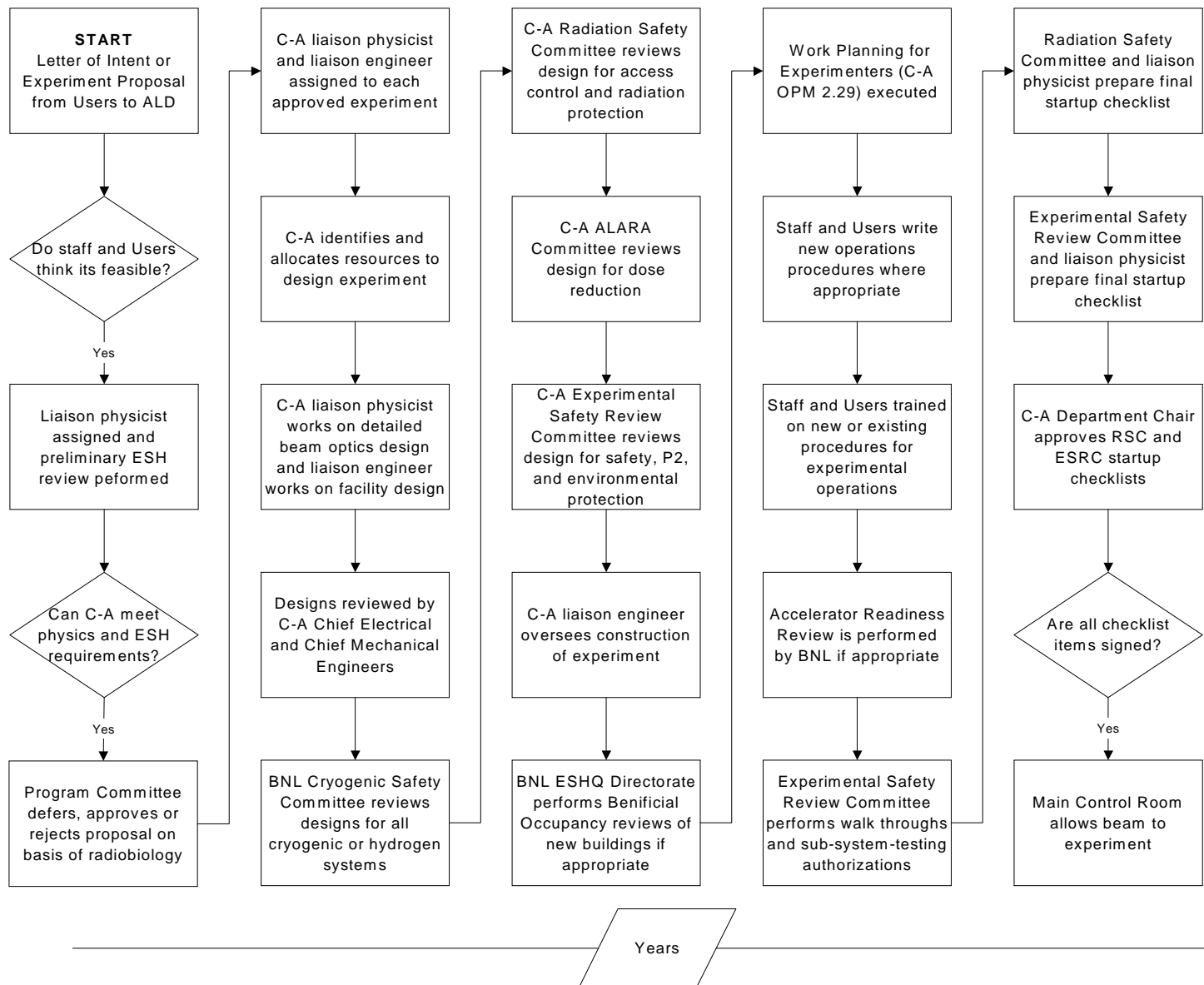
No other duties may be assigned to the gate watch such as checking training records or checking personnel dosimeters.

### 3.7. Experiment Design Criteria

Liaison Physicists, Liaison Engineers, Experiment Spokespersons and members of the Collider-Accelerator Experimental Safety Review Committee (ESRC) have primary responsibility for reviewing an experiment to ensure it meets design criteria. Experiment review within the Collider-Accelerator Department has many steps. A flow diagram of the experiment review process is shown in Figure 3.7 and it applies to the Booster Applications Facility experimental program as a whole. If there are no significant modifications or program changes to the experimental area during any given year, then the last 10 steps shown in Figure 3.7 are repeated before each running period. If proposed modifications or program changes to the experimental area exceeds the Accelerator Safety Envelope, then the whole process represented in Figure 3.7 is repeated.

It is noted that step 5 in Figure 3.7, Program Committee review of each experiment, also re-occurs before a running period. Only NASA-funded or NASA-approved investigators are eligible to submit proposals, and NASA carries the out peer-review for scientific merit. The Program Committee at BNL is the BNL Scientific Advisory Committee for Radiobiology. This Committee was established to advise the Associate Director for High Energy and Nuclear Physics on the scientific merits of biology-related experiments involving the use of particle accelerator beams in the Collider-Accelerator Department. Proposals approved by NASA are reviewed by the BNL's SACR for feasibility at BNL, and SACR suggests a priority of the experiments based on feasibility and importance to NASA.

Figure 3.7 Collider-Accelerator Department Experiment Review Process



The experiment design criteria complies with Laboratory requirements for planning and control of experiments as given in ESH Standard 1.3.5. However, the term Liaison Physicist as used within the Department is equivalent to the term Experiment Review Coordinator as used in ESH Standard 1.3.5. The term Experiment Spokesperson is equivalent to the term Lead Experimenter as used in ESH Standard 1.3.5.

At Collider-Accelerator Department, an experiment or experimental area may lie dormant for a period greater than one year between runs and not require a review during the dormancy period. The Department reviews each experiment or experimental area such as the Booster Applications Facility before a scheduled running period. The running period may be continuous for many months and overlap a fiscal year or a calendar year. A second annual review would not be required if Booster Applications Facility is in continuous operation for longer than 12 months and there are no significant changes to the experiment area. A running period significantly longer than 12 months is extremely unlikely for a facility like the BAF. On the other hand, if the Booster Applications Facility schedules more than one unique running period within a 12-month period, then review by the Experimental Safety Review Committee will occur before each scheduled run.

The Collider-Accelerator Experimental Safety Review Committee assures that the experiment's design does not exceed the approved Accelerator Safety Envelope, or the scope and impacts described in any pertinent National Environmental Policy Act document such as the Environmental Assessment. For "critical" safety items, defined as items that must be closed out before start of operations of the experiment, the Liaison Physicist is responsible for ensuring closeout. The Collider-Accelerator Department Chair approves all experiment installation and the start of experimental operations before each running period.

Before the ESH review, the Liaison Physicist, Liaison Engineer and/or the Experiment Spokesperson provide written descriptions of ESH issues and protective systems. Based on this written description, special subject-matter experts are called to join the Experimental Safety Review Committee for advice or review on an ad hoc basis. The experimenters are not allowed to operate or change experimental parameters beyond their approved ESH envelope until satisfactory review by the Committee and until the Experiment Spokesperson fulfills or resolves all pre-start Committee recommendations and closes all outstanding items. For changes beyond the approved envelope, the Liaison Physicist or the Experiment Spokesperson are responsible for notifying the ESRC Chair, or the C-A Associate Chair for ESHQ, early in the planning phase. For non-commercial experimental devices, the Liaison Physicist is requested to obtain a certification of the device from the Collider-Accelerator Department's Chief Electrical Engineer or Chief Mechanical Engineer. Chief Engineer certification procedures are defined in the [Operations Procedures Manual](#).<sup>31</sup>

The Experimental Safety Review Committee must document an environmental evaluation for each experiment in conformance with requirements in BNL's SBMS Subject Areas. Any materials presenting environmental considerations if released are examined. For example, the Committee or their designate, who is the Environmental Compliance Representative to the Collider-Accelerator Department, evaluates the

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<sup>31</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch09/09-02-03.PDF> Procedure for Chief Engineers to Certify Conformance of Devices

potential consequences of a break in a buried pipeline, a spill onto soil, or an accidental release to the air, sanitary sewer or storm drain, and any non-radioactive air emissions, radioactive air emissions, or liquid effluents.

Experimental procedures must comply with Conduct of Operations requirements for emergency procedures, operating procedures, training requirements and experienced staff during running periods. This is accomplished using the Work Planning for Experiments procedure in the Operations Procedure Manual.

Pollution prevention is examined by ensuring experimental activities that involve purchasing, using or disposing of hazardous material and/or radioactive material are reviewed to reduce waste generation whenever possible. The Experimental Safety Review Committee considers measures to avoid or reduce the generation of hazardous substances, pollutants, wastes and contaminants at the source. The experimenters must have plans to reuse, if practical, hazardous material that cannot be eliminated, and have plans to treat the remaining waste to reduce the volume, toxicity or mobility before storage or disposal. The Committee also ensures that experimenters have identified a disposal path for all anticipated wastes before the experiment.

Finally, the Experimental Safety Review Committee ensures that relevant [Facility Use Agreements](#)<sup>32</sup> are updated whenever affected by a modification to the Booster Applications Facility experimental areas.

### 3.7.1. Characteristics of the Experimental Equipment, Systems and Components Having Safety-Related Functions

High-precision irradiations are permitted by providing beams with a single ion with a narrow beam-energy width, free of neutrons and charged-particle fragmentation products and beams in a wide range of diameters. The basic beam parameters, which are beam energy, beam intensity, beam-profile flattening, and beam diameter, are all adjustable within the Booster or in the Booster Applications Facility transport line with a wide dynamic range for each parameter. The Booster Applications Facility does not include any compensators for beam energy or beam profile, or any mechanical collimators or absorbers beyond the last bending magnet.

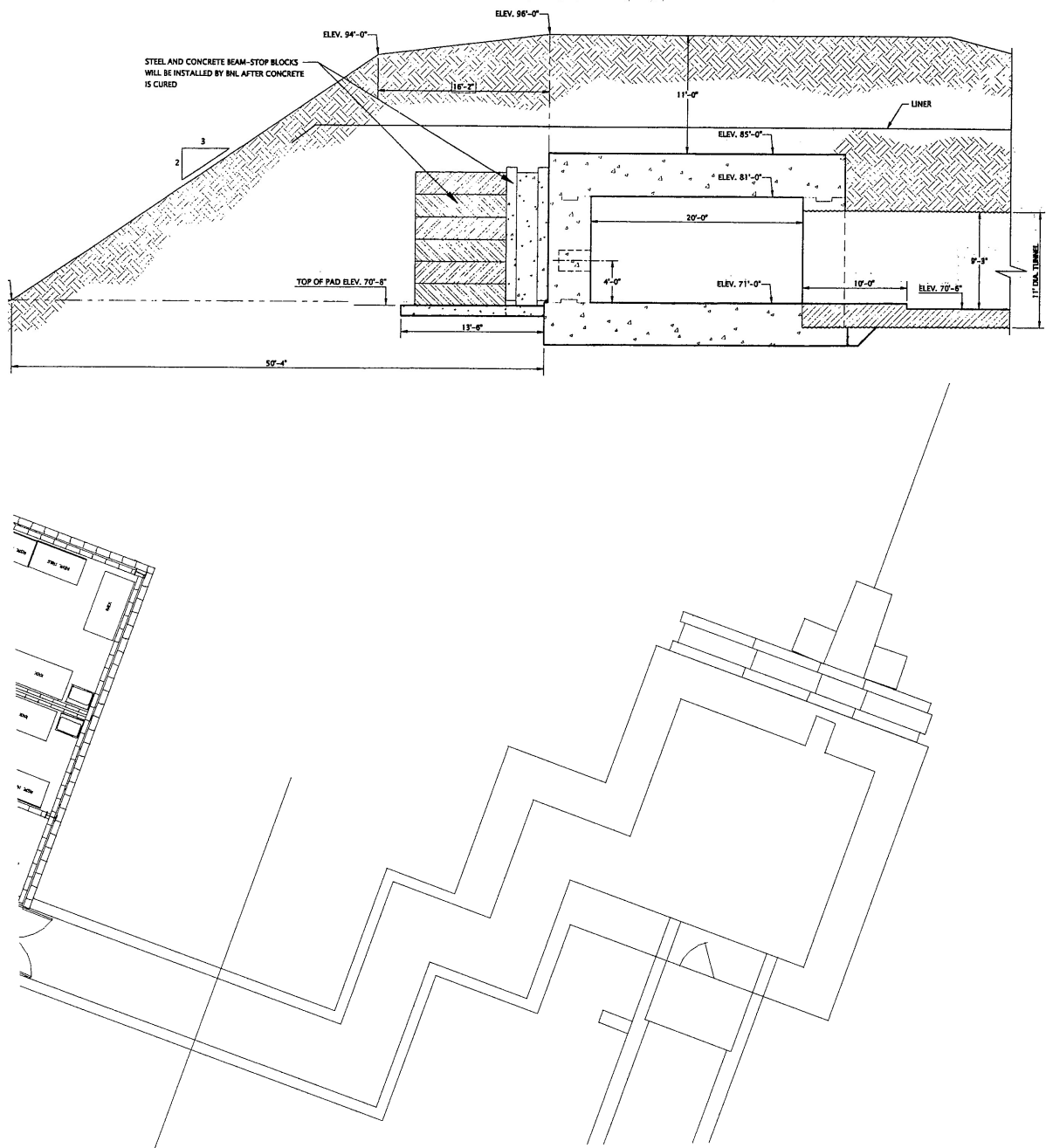
The layout of the Target Room is shown in Figure 3.7.1.a. A deeply recessed and well-shielded beam dump at the end of the Target Room prevents fragment products and backscattered particles from reaching the target. The beam dimensions will be adjusted to the target to minimize interaction of the beam with the target holder. If a target backing is necessary, such as the backing of the cell-culture targets, then the backing is made with the lightest materials possible. Other features of the Target Room that were introduced to facilitate safety during the experimental work are the following:

- The entrance to the room is gained through a maze. Therefore, entrance to the room after the completion of irradiation requires only opening of the interlocked safety partition and not any heavy shielded doors.
- The target holder is positioned by stepping motors controlled by the computer. Video cameras allow monitoring of the process from outside the Target Room.
- The Target Room is conveniently connected to the support laboratories, Figure 3.7.1.b.

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<sup>32</sup> <https://sbms.bnl.gov/private/fua/fa00t011.htm> BNL Facility Use Agreements

Figure 3.7.1.a Booster Applications Facility Target Room, Side and Plan Views



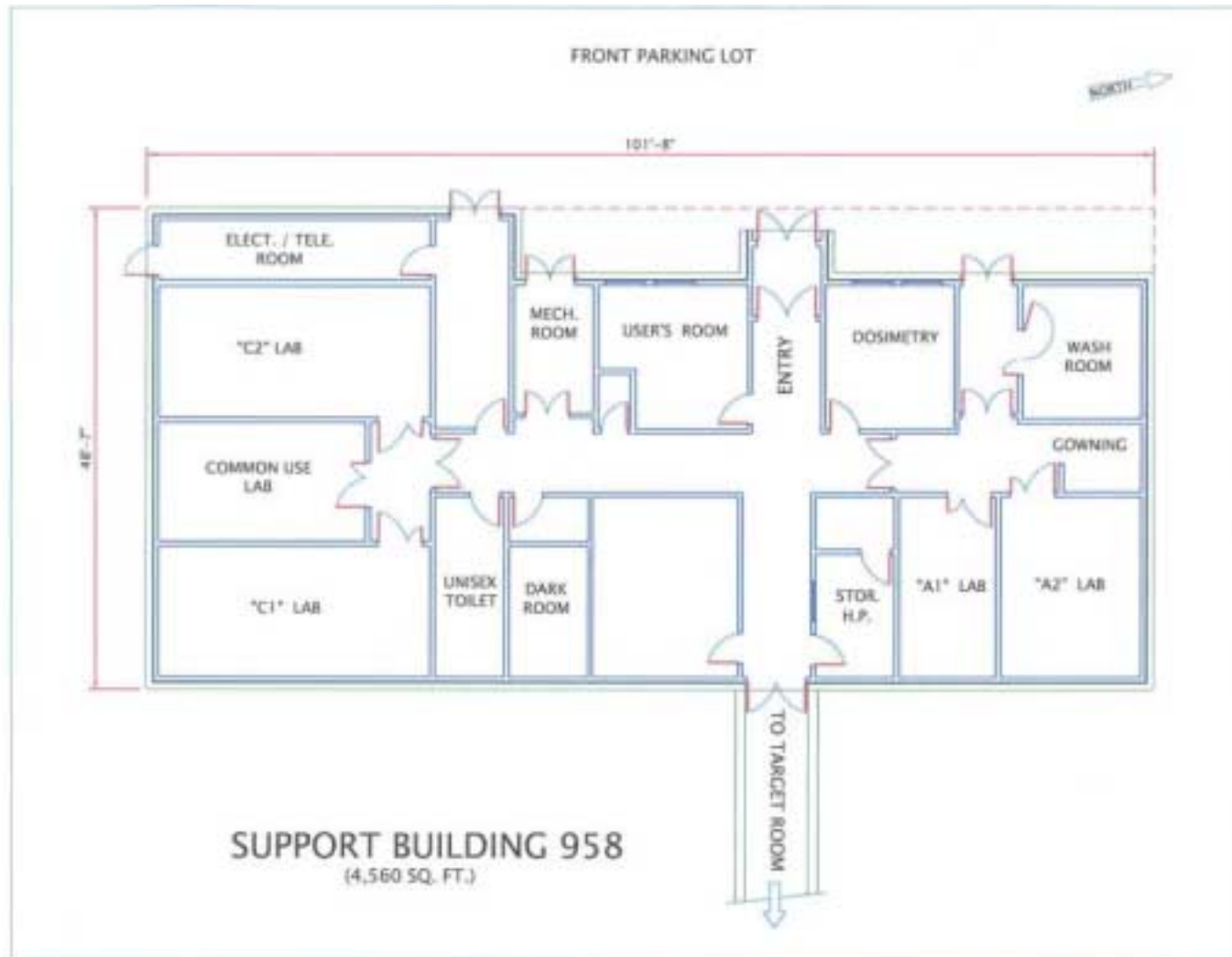
The Support Laboratories as shown in Figure 3.7.1.b lead to the Target Room, which is connected via a central hall. The Support Laboratories' layout maximizes use of beam time and facilitates experimental design and execution. All experimental rooms access the maze leading to the Target Room via the central corridor. A dosimetry room contains dosimetry computers, and communicates electronically with both the Collider-Accelerator Main Control Room and the user experiment rooms. Two rooms are provided for both the cellular experiments, and for animal studies; allowing one group to set up samples in an

experimental area while the previous group uses another experimental room, concludes their experiments in an ordered fashion, and takes all necessary time points. To comply with regulations for maintenance of animal facilities, a wash facility is provided off a side corridor onto which the animal experiment rooms also open. A janitor's closet is provided for storage of cleaning equipment and supplies. Further description of hazards in the A and C laboratories is given in Section 3.7.2, and the requirements for review of activities in these rooms is given in Section 3.7.3.

A Biophysics/Physics/Electronics experiment room, laboratory B, allows studies of effects on materials and electronics. Two wheel-chair-accessible rest rooms are accessed from a side corridor. A user room is provided for the investigators before and after beam use. To minimize cable length, the physics control room and the physics and electronics experiment rooms are in proximity to the gate leading to the maze. Two service entrances are provided with drive-up access and overhead shelter to allow off-loading of experimental samples and equipment in all weather conditions.

The Biophysics/Physics/Electronics Room, laboratory B in the Laboratory Support Building, is the staging location for studies of shielding materials or for studies on the shielding characteristics of space-bound solid materials. Experiment proposals associated with these types of studies are reviewed for science and feasibility by the SACR, and for safety and environmental issues by ESH specialists at the C-A Department. See Table 3.7.3 that shows the path from SACR to the C-A Work Planner for safety review and the C-A Environmental Compliance Representative for environmental review. Since these experiments do not involve biological materials and usually do not require laboratory space in the Biology or Medical Departments, Life Sciences Directorate Experimental Reviews and BNL institutional reviews, as described in Section 3.7.3, are not applicable.

Figure 3.7.1.b Booster Applications Facility Support Laboratories



The liaison physicist and the liaison engineer for the Booster Applications Facility presented the shielding design to the Collider-Accelerator Radiation Safety Committee, who reviewed the shielding against established criteria. A representation of the shielding is shown in Figure 3.7.1.c. Specific calculations of dose equivalent outside the shielding are found in [Appendix 1](#). Specific estimates of the induced activity in the beam stop and resultant dose rate inside the Target Room are provided in [Appendix 7](#). The Radiation Safety Committee concluded that the shield:

- Limits the annual site-boundary dose equivalent to less than 5 mrem.
- Limits the annual on-site dose equivalent in non-Collider-Accelerator facilities to 25 mrem per person.
- Limits the maximum accumulated dose equivalent to any area where access is not controlled to less than 20 mrem during a fault condition.
- Makes the dose equivalent rate as low as reasonably achievable (ALARA) and in no case is it greater than 0.5 mrem in 1 hour or 20 mrem in 1 week for continuously occupied locations.
- Makes the dose equivalent rates where occupancy is not continuous ALARA and in no case allows greater than 1 rem in 1 year for whole body radiation, or 3 rem in 1 year for the lens of the eye, or 10 rem in 1 year for any organ or tissue.

During the review, the Radiation Safety Committee examined the layout of the experimental area and the beam transport system. Possible radiation sources during fault conditions were examined. These possible sources included apertures, collimators, instrumentation, valves, magnets, targets, detectors and beam scraping in the beam transport pipe. Sources caused by improperly adjusted beam elements were also considered. Based on shielding and experimental requirements, the Committee then set the normal operating parameters for the Booster Applications Facility into the Committee records. For example, the Radiation Safety Committee approved primary beam energy, particles per second on target and the target parameters such as beam spot size. The Committee also established the radiological classification for Booster Applications Facility areas; that is, they reviewed and approved all designated Controlled Areas, Radiation Areas and High Radiation Areas. Area classifications were established for both normal and abnormal operating conditions.

On this basis, the Chair of the Collider-Accelerator Department's Radiation Safety Committee and the Associate Chair for ESHQ approved the shielding design and the shielding prints. The shielding prints were placed in configuration control, were assigned an identifying number and became a permanent record of the shielding for the Booster Applications Facility.

The Radiation Safety Committee also reviewed and approved the Access Control System for the Booster Applications Facility beam line and Target Room. They approved the critical devices and they established the conditions that the Access Control System must monitor; for example, the electric current on beam elements, the position of moveable beam components, and the position of access gates. They established the alarm level and interlock level for Chipmunk area radiation monitors. The Radiation Safety Committee also reviewed and approved the required fault studies. During the commissioning period, radiation surveys and fault studies will be conducted at Booster Applications Facility by the Radiation safety Committee to verify the adequacy of the shielding and the radiological area classification.

Environmental issues were also considered by the Radiation Safety Committee including soil activation, air activation, ground water activation and erosion of the soil-shield. The position of the protective geo-membrane cap that prevents rainwater leaching of the activated soil is show in Figure 3.7.1.c. Groundwater activation estimates are given in [Appendix 1](#). Airborne activity estimates are given in [Appendix 4](#). The soil-shield berm is re-vegetated and inspected routinely for soil erosion.

4" MIN. TOP SOIL, PROTECTED BY BURLAP MAT AND HYDROSEEDING

CONTINUOUS LINER OVER THE ENTIRE TUNNEL AND STRUCTURES. SEE DWG. C1 FOR THE BOUNDARIES OF THE LINER

6'-3" 6'-3"

ELEV. 94'-9"

8'-0"

COMPACTED FILL

ELEV. 87'-6"

2'-0" 2'-0"

ELEV. 83'-4" (±) ELEV. 83'-4" (±)

7'-0"

15'-4" (±) 15'-4" (±)

BAF BEAM EL. 75'-0"

2'-0"

7"1000" UNISTRUT @ 5'-0" O/C SHOP WELD TO TUNNEL PLATE

RS'-6"

ELEV. 74'-3"

ELEV. 70'-6" (SEE NOTE)

9 #4 CONT. #4 @ 12"

18"

4" CLEAN FINE SAND OVER COMPACTED SUBGRADE, SHAPE TO FIT THE STEEL TUNNEL CURVE

CONCRETE FLOOR

6" WIDE RECESS TO BE FILLED WITH FINE ASPHALT AFTER CONCRETE IS CURED

### 3.7.2. Biological Safety

The BAF user community determined their needs for biological support in proximity to the Target Room. For the majority of users, long-term experimental procedures will be carried out in their own institutions and in NASA-sponsored laboratories in the BNL Medical Department or Biology Department; BAF will provide only short-term holding facilities for biological specimens.

The experimental systems that the users proposed to investigate included:

- Cultured non-human mammalian cells
- Cultured human cells
- Primary human cells such as small samples of blood obtained in medical facilities under Institutional Review Board<sup>33</sup> approval and transported to BAF by approved means
- Isolated non-hazardous biological molecules, e.g., DNA
- Standard laboratory animals such as *Drosophila* (fruit flies), Nematodes (worms), chickens, rats and mice; investigators did not plan to use larger animals
- Non-biological materials such as shielding, space-suit materials and electronics including dosimetry equipment

Specific biological materials beyond those described here will be reviewed on a case-by-case basis by the BNL IBC.

Many of the cell systems used are Biosafety Level 1. However, the potential handling of human blood in the facility dictated that a Biosafety Level 2 facility be provided. Biosafety Level 2 practices, equipment and facilities are appropriate when any work is done with human-derived blood, body fluids or tissues where the presence of an infectious agent may be unknown.<sup>34</sup>

For Biosafety Level 2, facility design specifies that the cell rooms are separated from general public access areas and hand washing facilities be provided. To minimize external contamination of critical samples by increasing ease of facility cleaning and maintenance, scrub-able walls and poured-resinous seamless floors with closeable drains are specified. To prevent contamination, the Cell Facility has air circulation and ventilation that are separate from that of the Animal Facility. No extra biological hazard would be encountered if the ventilation system went off. However, the use of the Bunsen burner should be limited or ceased. All materials, including Regulated Medical Wastes, will be transported by the users back to the long-term facilities in the BNL Medical Department, and these transportation activities will be reviewed and approved during Experimental Safety Review. Transportation activities shall be in accord with SBMS Subject Area requirements.

Safety equipment includes Class II biological safety cabinets to provide significant levels of protection to laboratory personnel and to the environment when used with good microbiological techniques as well as protect the experimental samples from external contamination. Personal protective equipment (PPE) such as laboratory coats, gloves and safety glasses will be available. The Biological Safety Cabinet specified will be a Class II, Type A cabinet. It is appropriate for Biosafety Levels 2 and 3, but is not designed for volatile chemicals, as it re-circulates the air through a HEPA filter into the laboratory. A separate chemical hood

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<sup>33</sup> BNL Institutional Review Board (IRB) <https://sbms.bnl.gov/ld/ld16/ld16d051.htm>

<sup>34</sup> Biosafety in Microbiological and Biomedical Laboratories (BMBL) 4th Edition, HHS, CDC, U.S. Government Printing Office, April, 1999 <http://www.cdc.gov/od/ohs/biosfty/bmbl4/bmbl4toc.htm>

designed for the use of small quantities of volatile chemicals has been reviewed by BNL's Industrial Hygiene Group and will be located near the cell rooms. The hood is small enough to be classified as equipment and is not part of the facility structure.

Laboratory practice and technique used in the BAF will be standard microbiological practices and techniques. Persons using blood or other tissues with the possible hazard of Blood Borne Pathogens will receive appropriate training. All experiments using human cells and tissues will be reviewed by the BNL IRB as well as the IRB of the Users' institutions, as appropriate.

Laboratory-animals will be kept in the BAF for less than 24 hours and for USDA regulated species will be kept less than 12 hours. The animal facility was designed and constructed to facilitate cleaning and housekeeping. This includes poured-resinous, seamless floors and washable walls. The facility has its own entrance, and the wing of the BAF containing the animal facility is closed from the general corridor by double doors. The facility has its own air handling system, which is vented away from the intakes of the other air handling systems. No studies of infectious agents are anticipated. Animals and cages will be returned to the BNL Medical Department. Hot water hoses will be available for washing animal racks at BAF. The animal facility will be routinely monitored by BNL's Security Services Division.

There is no need to prohibit animals from the BAF in case of ventilation problems due to the limited amount of time animals will be housed there. The facility has locks on the doors and a card reader at the entry. All personnel entering the BAF animal facility will have previously been issued keys or key cards, and placed on a facility access list.

For non-biological materials, such as shielding, space-suit materials and electronics, no biological hazards are anticipated.

Access to the facility will be by card issued on a need-only basis. Transportation of experimental samples/ equipment, etc. to or from BNL will be by DOT rules; investigators are informed of this requirement when they register via the BNL Guest Information System and by the C-A Safety Review Form. They are required to state their arrangements for such transportation. Regulated medical waste and any Biohazards on-site will be transported, after appropriate packing, labeling and documentation of the material, according to BNL requirements in the SBMS Subject Area.

Current users have not proposed the use of recombinant DNA materials at BNL. In the context of the National Institutes of Health (NIH) Guidelines, recombinant DNA molecules are molecules that are constructed outside living cells by joining natural or synthetic DNA segments to DNA molecules that can then replicate in a living cell. Although improbable, some recombinant DNA may cause serious or lethal human disease. If use of recombinant DNA materials prepared at a user's home institution is proposed, then the user will submit a copy of the home institution's Institutional Biosafety Committee (IBC)<sup>35</sup> approval. Additionally, a copy of the risk assessment analysis, a transportation plan in accord with DOE and International Air Transportation Association rules, and a description of the material must be forwarded to the BNL IBC for their consideration and approval before approval to bring such material to the BAF is given. It is unlikely that recombinant material will be constructed at BNL; however, any such experiments would be reviewed by the BNL IBC and NIH Guidelines shall be followed.<sup>36</sup>

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<sup>35</sup> Institutional Biosafety Committee <https://sbms.bnl.gov/ld/ld16/ld16d341.htm>

<sup>36</sup> NIH Guidelines for Research Involving Recombinant DNA Molecules  
<http://www4.od.nih.gov/oba/rac/guidelines/GUIDELINjan01rev.pdf>

### 3.7.3. Experiment Hazards and Controls

The following hazards are summarized for experiments:

- Biohazards
- Ionizing radiation
- Volatile chemicals

The following hazard controls are summarized, in no specific order, for the experiments at BAF:

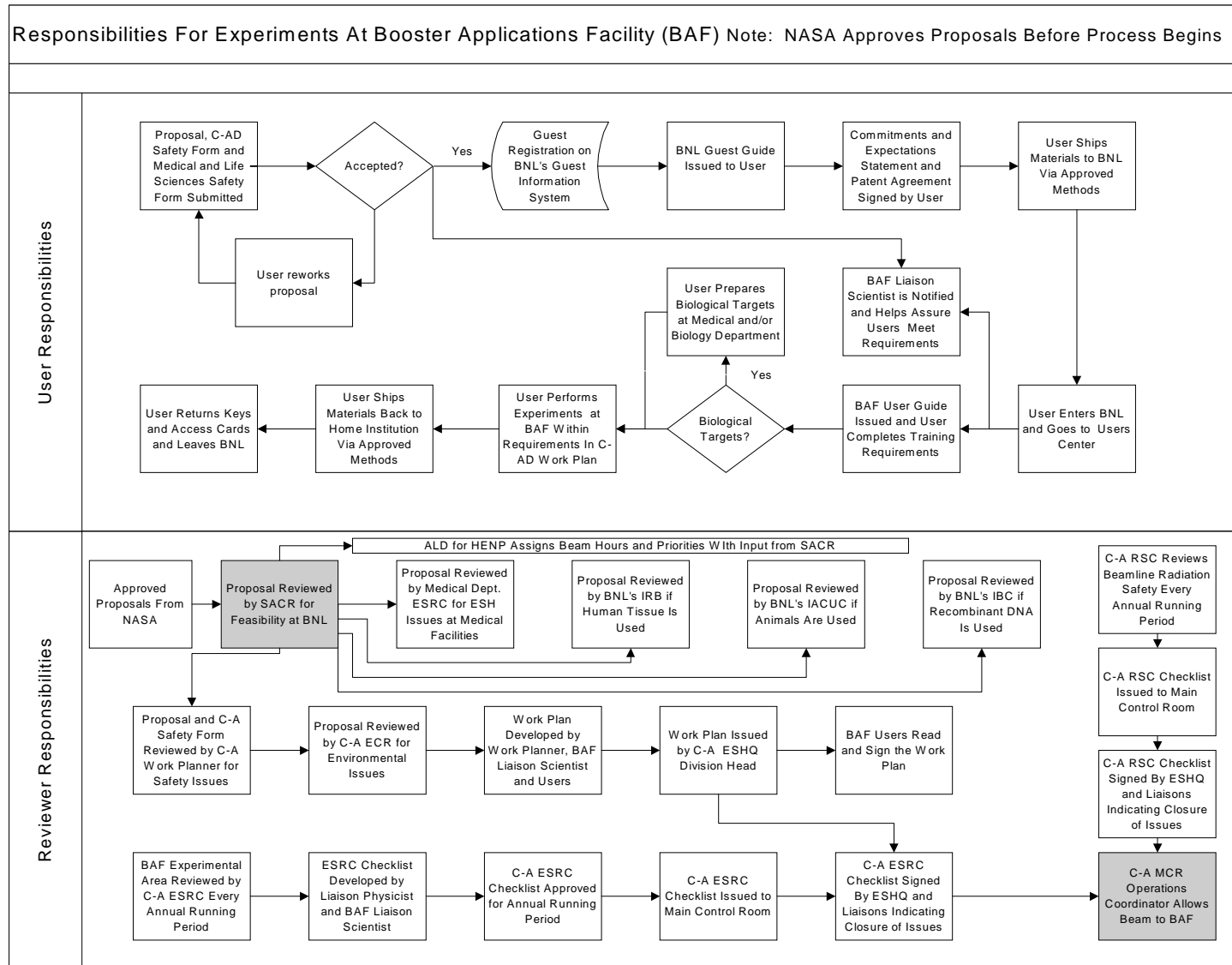
- Memorandum of agreement between Biology, Medical and C-A Departments listing responsibilities and authorities
- Only NASA-funded or NASA-approved investigators are eligible to submit proposals
- NASA carries out peer-review for scientific merit
- Proposals are reviewed by the BNL's SACR for feasibility at BNL, and SACR suggests a priority of the experiments based on feasibility and importance to NASA
- User completes a safety review form indicating hazards brought to BNL for each experiment
- IRB review for human cell and tissue experiments
- IBC review for experiments using recombinant DNA
- IACUC review for animal experiments
- Environmental Compliance Representative review of each experiment
- Medical and Biology Department's Experimental Safety Reviews
- Commitments and Expectations Agreement signed by each user
- Experiment work plan that is signed by each user that covers allowed work
- Building Manager assigned to BAF Support Laboratories
- Facility Use Agreement for BAF Support Laboratories
- Annual facility-specific user training for BAF for each user
- Other appropriate BNL training for guests
- Tracking system to ensure training is completed
- Formal schedule for experiment irradiations
- Annual review of the experimental areas by the C-A Experimental Safety Review Committee
- Quarterly review of the experimental areas by the C-A Safety Inspection Committee
- Biological Safety Cabinet, Class II, Type A, in the BAF Support Laboratory
- Biosafety Level 2 facilities in the BAF Support Laboratories
- HEPA filtered animal labs
- Segregated ventilation systems in the BAF Support Laboratories
- Lab coats, gloves and safety glasses and other appropriate PPE for users
- Bio-scanning device and key tree for user entry to BAF Target Room
- Card reader for user entry into the BAF Support Laboratories

A functional flow chart depicting responsibilities of the users and the reviewers, in the order they are performed, is shown in Figure 3.7.3. It is noted that activities at the BAF that are outside the boundaries for experiments described in Chapter 3 of the BAF SAD shall be reviewed by the C-A Experimental Safety Review Committee regardless of other reviews by BNL Committees or the Biology and Medical Departments. The following acronyms apply to Figure 3.7.3:

- ALD – Associate Laboratory Director

- C-A – Collider-Accelerator
- ECR – Environmental Compliance Representative
- ESH – Environment, Safety and Health
- ESHQ – Environment, Safety, Health and Quality
- ESRC – Experimental Safety Review Committee
- HENP – High Energy and Nuclear Physics
- IACUC – Institutional Animal Care and Use Committee
- IBC – Institutional Biosafety Committee
- IRB – Institutional Review Board
- MCR – Main Control Room
- RSC – Radiation Safety Committee
- SACR – Scientific Advisory Committee for Radiobiology

Figure 3.7.3 BAF Functional Responsibilities for Experiments



## 4. Chapter Four, Safety Analysis

### 4.1. Introduction

The Booster Applications Facility design is based upon successful designs employed at other BNL accelerators and experiments, and therefore, has the same favorable safety characteristics. The basic approach for the safety analysis has been to review the potential hazards for each major segment of the facility. Hazard analysis is the standard method for applying the DOE graded approach for minimizing risk. It is well suited to identifying and understanding risk because it requires consideration of both the likelihood and the potential consequences of hazards. The product of likelihood and consequence constitutes the risk. When using risk as the measure of acceptance, the allowable consequences for lower likelihood events are higher than for the higher likelihood events. In the hazard analyses presented in this chapter, the approach has been to evaluate the risk and to identify preventive and mitigating features that ensure that risk is acceptably low. Because the Booster Applications Facility project is following consensus codes and standards, standard industrial hazards are addressed and risks minimized without the need for detailed hazard analyses.

### 4.2. Hazard Analysis Approach

Hazard analyses include hazard identification and screening, assessment of the potential consequences of unmitigated risk, identification of relevant and effective mitigation/preventive measures, and finally, assessment of mitigated risk. Hazard analysis makes it possible to understand the risk and make informed risk acceptance decisions. It is desirable to be able to show that the Booster Applications Facility risks are in the “extremely low” category (see Table 4.2), and an effort to do so has been made in this section of the SAD. The hazard identification process used the Booster Applications Facility design and operating information; BNL site documents; facility walk-downs to identify potential hazards within the complex that could adversely affect the workers and environment; and discussions with the engineers and users of the Booster Applications Facility. The hazards evaluation process is a largely qualitative assessment of potential accidents or impacts in terms of hazards, initiators, likelihood estimates, preventive or mitigating features and public, environmental and worker consequence estimates. A maximum credible accident scenario is presented later in this chapter, the consequences of which bound all those to workers, the public and the environment. The results of these analyses confirm that the potential risks from Booster Applications Facility operations are extremely low. The hazards involve those present at existing BNL accelerators and experiments such as radiation, chemical, biological, electrical, magnetic fields, rf fields, energy sources, material handling, heights, rotating equipment, fire, explosions, natural phenomena, steam, heat and cold, confined spaces, lasers, compressed gas, etc. There are no unique hazards that are not already dealt with in a safe and efficient manner.

Table 4.2 The Risk Matrix

↑ Consequence Level

High <sup>(Note 1)</sup>	Low Risk – Acceptable	Medium Risk- Unacceptable	High Risk- Unacceptable	High Risk- Unacceptable
Medium	Extremely Low Risk - Desirable	Low Risk – Acceptable	Medium Risk- Unacceptable	High Risk- Unacceptable
Low	Extremely Low Risk - Desirable	Extremely Low Risk - Desirable	Low Risk – Acceptable	Medium Risk- Unacceptable
Extremely Low	Extremely Low Risk - Desirable	Extremely Low Risk - Desirable	Extremely Low - Desirable	Low Risk – Acceptable
	Extremely Unlikely (<10 <sup>-4</sup> /y)	Unlikely (Between 10 <sup>-4</sup> /y and 10 <sup>-2</sup> /y)	Anticipated <sup>(Note 2)</sup> Medium (Between 10 <sup>-2</sup> /y and 10 <sup>-1</sup> /y)	Anticipated <sup>(Note 2)</sup> High (Above 10 <sup>-1</sup> /y)

Likelihood of Occurrence →

Note 1: Definition of Consequence Levels -

- Extremely Low: Will not result in a significant injury or occupation illness or provide a significant impact on the environment.
- Low: Minor onsite with negligible or no offsite impact. Low risk events are events that may cause minor injury or minor occupational illness or minor impact on the environment.
- Medium: Medium risk events are events that may cause considerable impact onsite or minor impact offsite. Medium risk events may cause deaths, severe injuries or severe occupational illness to personnel or major damage to a facility or minor impact on the environment. Medium risk events are events from which one is capable of returning to operation.
- High: High-risk events may cause serious impact onsite or offsite. High-risk events may cause deaths or loss of facility/operation. High-risk events may cause significant impact on the environment.

Note 2: 10CFR835 may require limits that are more stringent for anticipated events.

#### 4.3. General Approach to Risk Minimization

Hazard identification produces a comprehensive list of hazards present in a process or facility, and the screening phase removes all hazards that are below a threshold of concern, or that are covered by recognized industrial codes and standards. The hazards that are “screened out” do not need to be studied in detail because their risks are already well understood and acceptable. This process is a creative multi-person examination of the processes, operations and experiments related to Booster Applications Facility. A hazard is a source of danger with the potential to cause illness, injury or death to personnel, damage to an operation or cause environmental damage.

For each screened hazard retained for detailed hazard analysis, the unmitigated risk is first evaluated in terms of likelihood and consequence. This evaluation is done using professional engineering judgment based on experience with other BNL accelerators and experiments. This places the hazard on the risk matrix (see Table 4.2). The following assumptions govern the determinations of unmitigated risk:

- The unmitigated risk does not include safety or control systems.
- Assigned frequencies are based on engineering judgment.
- Assigned consequence can be qualitative, but must be conservative.
- If the unmitigated risk is extremely low, then the analysis can stop at this point. Otherwise, one proceeds to the evaluation of mitigated risk.

The unmitigated risk is reevaluated considering the preventive and mitigating factors in place that would either reduce the consequence or reduce the frequency. This should move the location on the risk matrix based on assumed conditional probabilities of failure for the mitigating systems. At this point, the mitigated risk should be either low or extremely low. For low risk, the evaluation of the hazard is reviewed to determine if there are additional preventive or mitigating features that could be credited to bring the risk to extremely low. The last step is to determine if it is necessary to designate any Safety Significant equipment, make commitments for formal administrative controls, or specify limits for operation.

The purpose of Safety Significant designation is to highlight a minimum number of structures, systems or components needed to ensure safety. The number of designated Safety Significant items and administrative controls and limits must be minimized so that they can be treated specially and considered for incorporation in the Accelerator Safety Envelope (ASE), appropriate procedures and/or quality assurance documents.

If the unmitigated consequence is fatal for one or more persons or a significant environmental impact can occur, then a Safety Significant designation, in general, should be made. If there are several mitigating or preventive features, and any single one can control the hazard adequately, then it may not be necessary to designate a Safety Significant feature.

Table 4.2 allows binning of the hazardous event by its risk, which is a combination of the consequence of the hazardous event and its likelihood of occurrence. Some of these combinations are deemed acceptable, meaning these lower risk bins are adequately addressed by the qualitative hazard evaluation process. Other, higher risk bins are labeled unacceptable because the accidents within these bins require additional quantitative analysis to determine the true mitigated risk.

#### 4.4. Risk Minimization Approach for Radiation Hazards

The risk of a serious radiation injury at BNL accelerators, including Booster Applications Facility is insignificant. However, for radiation exposure it customary to go beyond the scope of Hazard Analysis to demonstrate that transient events, such as credible beam faults, do not cause annual radiation dose goals or requirements to be exceeded. The special status of radiation hazards is exemplified in the As Low As Reasonably Achievable (ALARA) requirement in the BNL RadCon Manual that exposure to radiation is to be minimized and driven as far below the statutory limits as is practicable. Some Booster Applications Facility areas are controlled access areas. The radiological areas (Controlled Area, Radiation Area, etc.) are established to control the flow and behavior of workers in each area such that workers receive the minimum radiation exposure coincident with operating the facility, which is the risk, to achieve its authorized research mission, which is the benefit. These areas are set with the expectation that radiation levels will not exceed certain specified maxima depending on the type of zone. The designated area maxima will be satisfied considering both the base level of residual radiation fields and the integrated effect of the short bursts typical of credible beam faults. The C-A Operations Procedure Manual, in compliance with the BNL Radiation Control Manual, lists the different areas including the required controls used at the Booster Applications Facility for minimizing exposure to external radiation. Significant contamination and internal uptake of radionuclides at Booster Applications Facility is extremely unlikely and further analyses of these issues are not necessary, and are documented in a [Technical Basis for Bioassay](#).<sup>37</sup>

#### 4.5. Hazard Identification and Hazard Analysis

This section describes the hazard identification and qualitative hazard analysis for each of the major portions of the Booster Applications Facility: beam transport systems, beam dump systems, target and support building, power supply building, cooling water systems, shielding and instrumentation systems. The results of the hazard identification and analyses are given in [Appendix 9, Qualitative Risk Assessment](#).

The hazard identification process examined the Booster Applications Facility processes and operations that could result in a source of danger with the potential to cause illness, injury or death, damage to operations or environmental damage. The Booster Applications Facility design documentation, BNL conventional and radiological safety requirements, Booster Applications Facility walk downs, C-A Operating and Emergency Procedures, and discussions with engineering staff, experimenters and safety professionals were utilized to conduct the detailed hazard identification and hazard analysis of the Booster Applications Facility.

##### 4.5.1. Conventional and Environmental Hazards

A review of all safety and health issues related to the Booster Applications Facility leads to the conclusion that fire, radiation and electrical hazards require further

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<sup>37</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/Bioassay/BioassayTechBasis.doc> Technical Basis for Bioassay Requirements, Collider-Accelerator Department, January 2001.

safety analysis, which considers the preventive and mitigating Booster Applications Facility design features. Documentation of the hazard screening is found in [Appendix 9](#).

Pressure and vacuum vessels, use of toxic, hazardous and biological materials, use of flammable/inert/cryogenic gases/fluids, noise, hoisting/rigging, lasers, rotating equipment, heat and magnetic fields are considered routine activities. The risks from these activities are maintained acceptable by compliance with the requirements of the BNL Standards Based Management System (SBMS) Subject Areas and the C-A Operations Procedure Manual. When required, these hazards undergo review by the appropriate BNL or C-A committee or they undergo review by C-A ESHQ Division specialists during the work planning process, as indicated by C-A OPM or SBMS requirement.

Electrical safety is a very serious and complex subject, which is controlled by experienced C-A and BNL staff engineers, operators, technicians and maintenance personnel. A full description of the electrical safety requirements that assure electrical safety is given in the BNL Standards Based Management System. Routine access to the Booster Applications Facility Target Room is not prohibited when the magnets are powered. However, access to the tunnel from the Target Room is prohibited for Users by a locked gate. The closest beam-line magnet is almost 50 feet upstream of the Target Room. Access to the tunnel by trained and authorized C-A support staff to investigate a magnet problem is covered by a C-A OPM procedure and a working hot permit.

Static or fringe magnetic fields that are present in the Booster Applications Facility transport magnets do not warrant special controls other than appropriate warning signs and training of personnel who have access to Booster Applications Facility.

A list of chemicals used in the C-A facilities, the annual quantity used and the manufacturer's Material Safety Data Sheets are maintained in accordance with the BNL Chemical Safety Program. Required reviews of the conventional safety aspects of the C-A facilities shows that use of these chemicals does not warrant special controls other than appropriate signs, procedures, appropriate use of personal protective equipment, and hazard communication training, all of which have been implemented. Reviews are carried out before work, via the work planning process.

With regard to environmental impacts, the effluent hazards include generation of  $^3\text{H}$  and  $^{22}\text{Na}$  in the earth shielding, which could potentially contaminate the ground water, and generation of short-lived radioactive gases in the air in the tunnel and Target Room. Both of these are addressed in this Chapter of the report, and these hazards have been eliminated or controlled by design. Even though tritium levels in cooling water are less than the Drinking Water Standard, the intent of Suffolk County Article 12 Code was followed in the design of cooling water systems and piping that contain trace amounts of tritium. Diversion of radioactive liquid effluent from the sanitary waste system to a hold-up system, or hold up of radioactive liquid in C-A sumps, occurs in order to allow retention and sampling before disposal. Air emissions from Booster Applications Facility are negligible since the potential activation products are sufficiently low; that is, much less than 0.1 mrem/year to the public, to assure doses are ALARA. Results of environmental monitoring and details on exposure pathway analysis are found in the annual BNL Laboratory Environmental Report produced by the BNL Environmental Services Division.

#### 4.5.2. Radiation Hazards

The BNL accelerators and experimental beam lines have been in operation for over 40 years providing protons and polarized protons for the high-energy physics program, and in addition, for the past 12 years, the accelerators have been providing heavy ions for the nuclear physics and NASA programs. Among the three operating modes of the AGS, high flux unpolarized proton beam, polarized proton beam and heavy ion beams, the high flux unpolarized proton operation represents the greatest ionizing radiation hazard because they can provide the highest intensity beam. Fault calculations for Booster Applications Facility shielding and activation are based on fluxes associated with unpolarized protons. For routine operations, calculations are based on heavy-ion particle flux given in [Appendix 3](#). For calculation purposes, each nucleon in a heavy-ion nucleus, either proton or neutron, is treated as an independent high-energy particle.

The principal radiation hazards associated with the Booster Applications Facility derive from the primary beam flux and duty cycle for Booster Applications Facility operation. Listed in order of importance, these hazards include:

- Inadvertent exposure of workers to primary beam.
- Exposure to secondary radiation created by primary beam losses during normal operation or episodes of abnormal losses.
- Exposure to residual radiation induced in machine components and in the beam dump and Target Room.
- Inadvertent release of activated cooling water to the environment.
- Inadvertent release of radioactive contamination to groundwater by allowing rainwater to leach through activated soil.
- Exposure to activated air.

#### 4.5.3. Source Terms

In estimating the degree of radiation risk, the shielding is designed assuming the routine and maximum operating beam for the facility as indicated in Table 4.5.3. The shield is designed to mitigate the greatest radiation hazard, which are unpolarized protons. Thus, the shield is more than adequate for protection against polarized proton or heavy ion loss because their intensity and/or individual nucleon energies are much less by comparison.

A baseline evaluation of radiation hazards associated with operation and construction of the Booster Applications Facility is included as [Appendix 1](#). Since completion of [Appendix 1](#), several changes have occurred including a modest increase in the limits on beam in the Booster Applications Facility line and a better understanding of how the facility will operate. In this Report, the results of [Appendix 1](#) are updated using the revised assumptions from Table 4.5.3. Specifically, estimates of the following hazards are given here:

- Prompt radiation immediately outside the earth shield (berm).
- Prompt radiation at the support and target building.
- Skyshine.
- Potential activation of groundwater if the berm is uncapped.
- Activation of air in the Target Room.

Some additional topics were addressed in [Appendix 1](#), which are not discussed here<sup>38</sup>.

Table 4.5.3 Summary of Routine, Maximum and Faulted Beam Operating Assumptions for Booster Applications Facility

Quantity	Maximum Value
Annual Energy Flux from Booster SEB	$10^{17}$ GeV in one year
Hourly Energy Flux from Booster SEB	$6 \times 10^{14}$ GeV in one hour
Annual Energy Flux on the Booster Applications Facility Beam Stop	$3 \times 10^{16}$ GeV in one year
Hourly Energy Flux on the Booster Applications Facility Beam Stop	$6 \times 10^{14}$ GeV in one hour
Annual Energy Flux on Booster Applications Facility Targets (0.25 nuclear interaction lengths)	$3 \times 10^{16}$ GeV in one year
Hourly Energy Flux on Booster Applications Facility Targets (1.0 nuclear interaction length)	$6 \times 10^{14}$ GeV in one hour
Maximum, Single Event, Non-routine Point Loss at any Location <sup>39</sup>	$6.75 \times 10^{15}$ GeV

#### 4.5.4. Results of Calculation for Radiation Levels

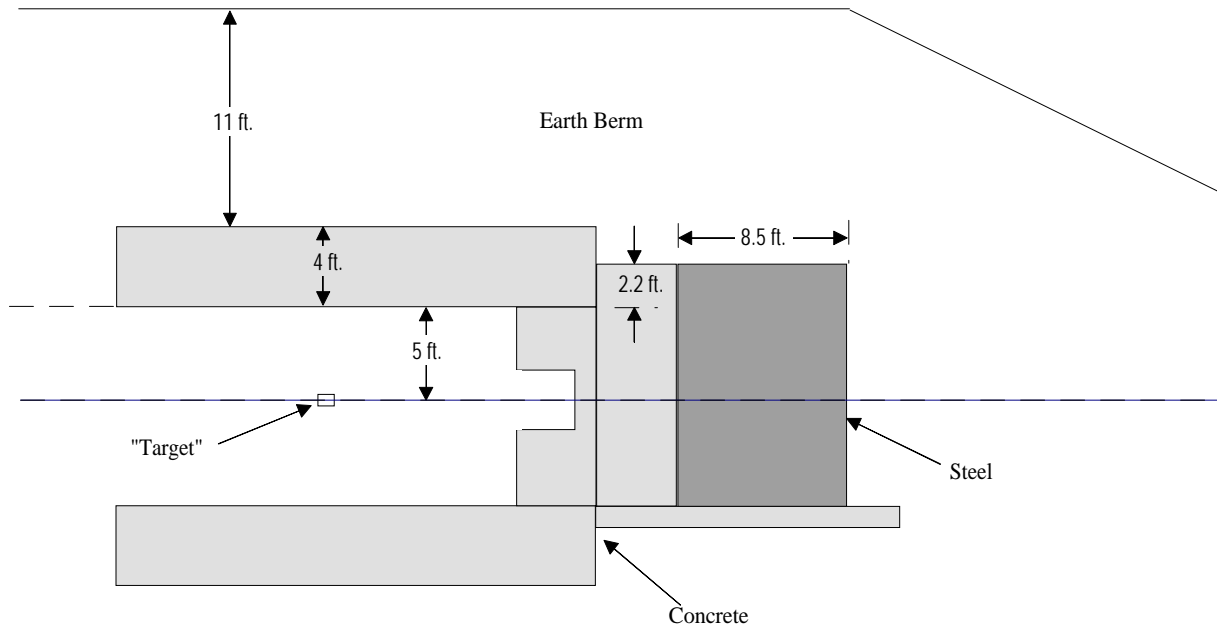
An elevation view near the Target Room and beam dump is shown in Figure 4.5.4.a. The prompt radiation at the edge of the berm above the target in the Target Room, which is the point of minimum shield thickness, was computed using the Tesch formula for 3.07 GeV protons.<sup>40</sup> This dose was found to be  $2.42 \times 10^{-17}$  rem per proton. Table 4.5.3 prescribes a maximum hourly limit of beam interacting on target to be  $6 \times 10^{14}$  GeV, which would result in 4.73 mrem per hour. Averaged over a year, the hourly dose is much less. From [Appendix 1](#) and for a “thick target” the average GeV per hour is  $2 \times 10^{13}$  versus the  $6 \times 10^{14}$  considered above, for a reduction factor of 0.033, or an average dose rate of 0.16 mrem/hr.

<sup>38</sup> Appendix 1 also considered beam loss in the Booster tunnel due to Booster Applications Facility operation and a potential hazard relevant to Booster Applications Facility construction from a Booster fault condition.

<sup>39</sup> The maximum, single-event, non-routine point loss is  $1.5 \times 10^{14}$  5-GeV nucleons/sec for 9 seconds. Nine-seconds is the assumed response time of fixed-area radiation monitors to interlock the beam. Thus, a single-event, high-energy nucleon loss of  $6.75 \times 10^{15}$  GeV is the maximum fault assumption for any location at Booster Applications Facility. It is noted in BNL Memorandum, J. Geller to D. Beavis, RSC Chair, “Time to Chipmunk Interlock for Large Radiation Faults,” March 2, 1999 that tests of the internal chipmunk circuitry yield an absolute minimum response time of 0.65 seconds. Nine seconds is taken to include the response time of the external circuitry that includes relays and critical devices.

<sup>40</sup> K. Tesch and H. Dinter, Radiation Protection Dosimetry, Vol. 15 No. 2 pp. 89-107 (1986). See Appendix 1.

Figure 4.5.4.a Elevation View of Target Room and Dump Region



The dose on the berm slope shown in Figure 4.5.4.a next to the beam dump was compared to the dose at 90° with respect to the target on the top berm using the CASIM program for high-energy particle *cascade-simulations*.<sup>41</sup> The result was that the dose on the slope is less than at the berm top. Thus, the hourly dose rates at the top of the berm are bounding, even for the situation where no target is in place.

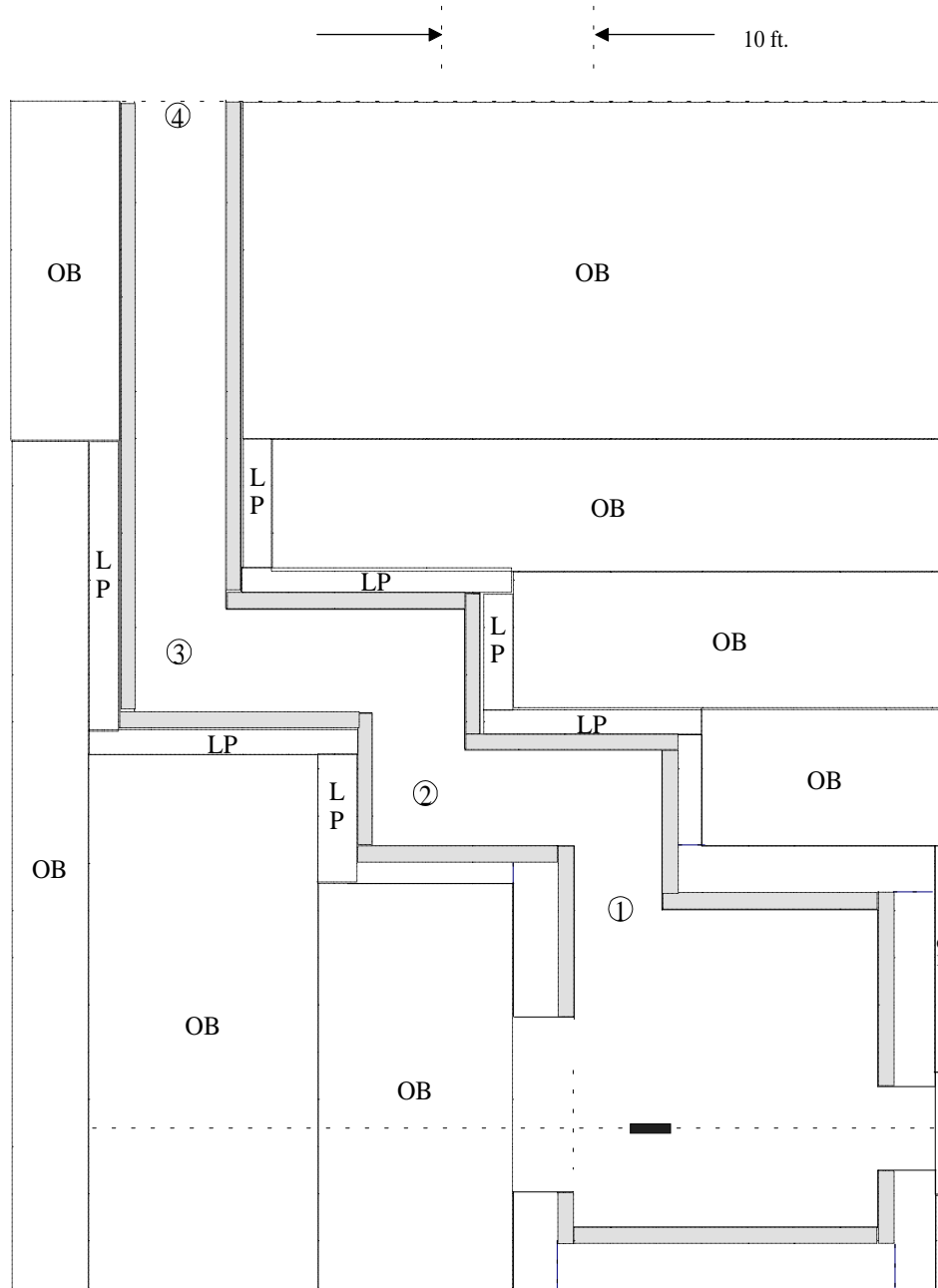
As indicated in Figure 4.5.4.a, upstream of the Target Room the shielding consists of 15 feet of earth. At the edge of the berm here, the Tesch formula gives  $4.52 \times 10^{-17}$  rem per proton. Assuming a 5% inadvertent loss of the maximum hourly limit ( $3 \times 10^{13}$  GeV) gives 0.44 mrem/hr. The average hourly dose rate corresponding to a chronic 5% inadvertent loss is a factor of 0.033 less, which is a dose rate of 0.015 mrem/hr. The assumption of a hypothetical 5% loss just before the target is based on experience with the final focusing magnet in a beam line at AGS; however, it is noted that operators monitor losses and are required to reduce beam losses to ALARA levels.

The prompt radiation at the nearest point in the Target Room is estimated by evaluation of the labyrinth shown in Figure 4.5.4.b. The estimate was made using the MCNPX code, as described in [Appendix 1](#). The dose at door of the support building, which is the circled 4 in the figure, for 3.07 GeV protons incident on a 12 cm plastic target, which is 0.16 interaction length, is  $10^{-18}$  rem per proton. The maximum hourly dose is obtained by assuming  $6 \times 10^{14}$  GeV on a one interaction length target. It is assumed that neutrons dominate the dose at the support building labyrinth-door. The re-entrant dump design supports this assumption. The resultant maximum dose rate is 0.84

<sup>41</sup> The CASIM code overestimates the dose in the forward direction when compared to the actual condition estimated by improved codes such as MCNPX at the GeV energy scale.

mrem per hour. The average hourly rate assumes a 0.25 interaction length target. Combining this with the average  $2 \times 10^{13}$  GeV per hour gives 0.01 mrem per hour.

Figure 4.5.4.b BAF Labyrinth from Target Room to Support Laboratory



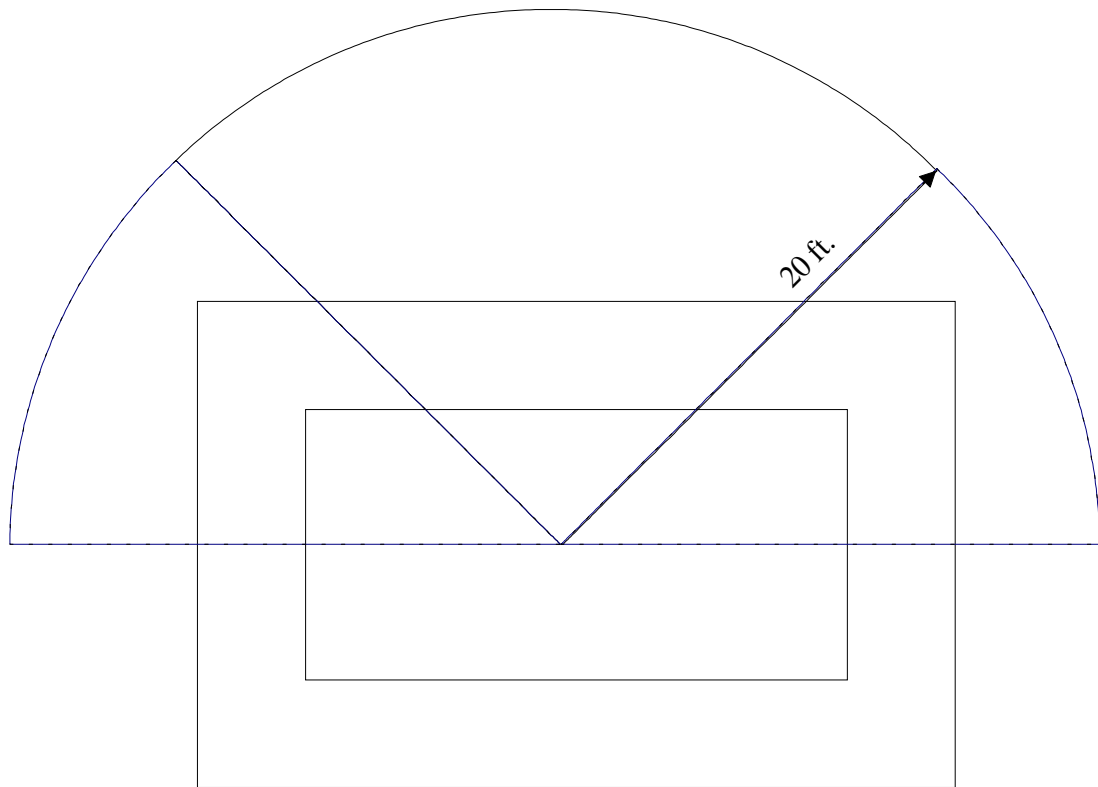
(The Labels LP and OB Refer to "Low Probability" and "Out-of-Bounds" Regions in the MCNPX Calculation)

Both the skyshine dose-rate estimate and the groundwater activation estimate, described later in this Report, are sensitive to targeting conditions. The maximum flux values listed in Table 4.5.3 assume that the beam can be incident on either a target or the

beam stop 100% of the time. Since this condition was not envisaged at the time of the initial estimates reported in [Appendix 1](#), new revised calculations were made. However, the techniques were not changed, so the reader is referred to [Appendix 1](#) for a more complete description.

The skyshine dose rate was determined by first estimating the number of neutrons greater than 20 MeV emerging from the earthen berm surface, then applying a skyshine formula developed from past measurements made at the AGS. The estimate of the number of neutrons was made from CASIM calculations performed at a 2 GeV incident energy in a simplified approximation of the geometry, a geometry that overestimates the emerging neutrons. Specifically, the berm was assumed to have a circular transverse cross-section, and the neutrons were summed over a  $\pm 45^\circ$  section centered on the beam line. A schematic cross section at the target position is shown in Figure 4.5.4.c.<sup>42</sup>

Figure 4.5.4.c Cross Section at Target Position Showing Skyshine Approximation



CASIM estimates were made with both the beam incident on the beam dump and on a 0.25 interaction length plastic target. The worst case was with the target present,

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<sup>42</sup> This is a slightly different approximation than was made in Appendix 1.

where the number of neutrons greater than 20 MeV per 2 GeV proton is  $2 \times 10^{-5}$ . For  $1.5 \times 10^{16}$  2-GeV protons per year, the skyshine formula from [Appendix 1](#) becomes:<sup>43</sup>

$$\text{rem/year} = \frac{0.125 \times e^{-D/600} \times (1 - e^{-D/47})}{D^2}$$

where D is the lateral distance from the source to the dose point of interest in meters. The closest building that at times is uncontrolled is Building 919 at D = 70 m. At this distance, the computed dose rate is about 0.02 mrem/yr.

Groundwater activation from beam interactions in or near the Target Room is also sensitive to the targeting conditions. Again, new CASIM calculations were made for the beam incident either on a 0.25 interaction length plastic target or on the dump. The transverse size of the beam was also varied.

The technique for estimating groundwater activation is described in [Appendix 1](#). The time-averaged transport of  $^3\text{H}$  and  $^{22}\text{Na}$  concentrations from the position of their creation to the water table by the leaching action of rainwater is estimated. This leachate concentration is required to be less than 5% of the drinking water standard as per the [Standards Based Management System](#).<sup>44</sup> The drinking water standard is 20,000 pCi/L for  $^3\text{H}$  and 400 pCi/L for  $^{22}\text{Na}$ . If this condition is not met, then geo-membrane liners or caps are required to cover the soil. These caps act like umbrellas to prevent leaching of the radionuclides from the soil to the water table.

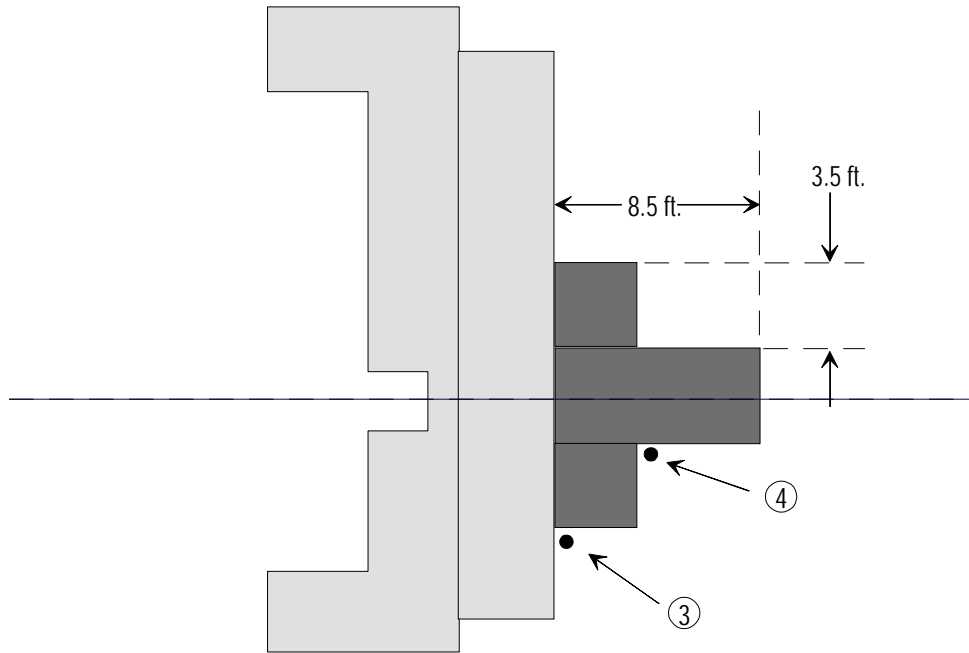
The quantity calculated to determine the soil radionuclide content is the CASIM “star density.” This is the interaction density of hadrons above about 47 MeV. Approximately 0.075  $^3\text{H}$  and 0.02  $^{22}\text{Na}$  are created “per CASIM star.” More information is given in [Appendix 1](#).

A search was made for the highest star density in soil. Figure 4.5.4.d shows a plan view of the dump region on the vertical mid-plane. The highest star density was found to be at the point labeled with the circled “4” for a very large beam incident directly on the dump. The value of  $2.6 \times 10^{-8}$  stars/cc-p for 3.07 GeV protons is slightly higher than given in [Appendix 1](#). The total stars per year is obtained by scaling to  $1.5 \times 10^{16}$  2-GeV nucleons to obtain a star density of  $2.8 \times 10^8$  stars/cc-year. Using the leaching model described in [Appendix 1](#), this results in a “hot spot” of 706 pCi/L of  $^3\text{H}$  and 85 pCi/L  $^{22}\text{Na}$ . Since 5% of the drinking water standard for  $^{22}\text{Na}$  is only 20 pCi/L, a liner is required over the dump. The  $^3\text{H}$  concentration is only 3.5% of the drinking water standard. Another CASIM calculation was performed by simulating an upstream loss by forcing protons to interact over a length of one meter in the beam pipe in a bare tunnel. If chronic loss of 5% of the beam is assumed, the result is a factor of three lower than quoted above. Thus for  $^{22}\text{Na}$ , the 85 pCi/L is scaled down to 28 pCi/L for this scenario. It is noted that a liner is installed over the entire beam line from the extraction point at the Booster to the Booster Applications Facility beam dump.

<sup>43</sup> The calculation in Appendix 1 was performed with a 12-cm long Fe target.

<sup>44</sup> <https://sbms.bnl.gov/standard/1r/1r00t011.htm> Accelerator Safety Subject Area

Figure 4.5.4.d Plan View of Target Room Dump Region



The air activation estimate, as the estimate made for prompt radiation at the entrance to the Target Room labyrinth in the support building, was made using MCNPX. The current values were scaled from the results given in [Appendix 1](#). However, one significant change has been noted in the intended operation, namely that the vacuum pipe, which had been thought to exist up to the target, actually terminates 5 feet upstream of the Target Room. The beam path length in air, which was assumed 10 feet in [Appendix 1](#), was therefore increased to 28 feet including the length of the re-entrant beam dump cavity.

With a correction for the target thickness used in the estimate described in [Appendix 1](#), the room-averaged hadron flux greater than 20 MeV from interactions becomes  $2.1 \times 10^{-6}$  per  $\text{cm}^2$  per incident 2-GeV proton, and the thermal neutron flux becomes  $3.4 \times 10^{-6}$  per  $\text{cm}^2$  per proton. However, the room averaged flux of the incident beam particles increases to  $6.8 \times 10^{-6}$  per  $\text{cm}^2$  per proton, which dominates the activation of air.

Given these fluxes, concentrations of various radionuclides are estimated using the cross sections given in [Appendix 1](#). For  $^{39}\text{Cl}$  and  $^{38}\text{Cl}$ , produced by spallation reactions with the argon in Target Room air, cross sections were estimated from Rudstram. These were included because they are sometimes detected in air samples at BNL accelerators. With the annual  $3 \times 10^{16}$  GeV per year given in Table 4.5.3, the following annual-activity concentrations averaged over the Target Room volume are computed conservatively ignoring radioactive decay and Target Room ventilation:

Table 4.5.4.a Annual-Activity Concentration Averaged over Target Room Volume  
and  
Annual Production Rate of Air Activation Products

Radionuclide of Interest	Volume Averaged Annual-Activity Concentration, Ci/cc	Annual Production Rate, Ci/yr
<sup>41</sup> Ar	$2.2 \times 10^{-11}$	$2.6 \times 10^{-3}$
<sup>39</sup> Cl	$1.2 \times 10^{-16}$	$1.4 \times 10^{-8}$
<sup>38</sup> Cl	$4.3 \times 10^{-16}$	$4.9 \times 10^{-8}$
<sup>35</sup> S	$1.4 \times 10^{-15}$	$1.6 \times 10^{-7}$
<sup>32</sup> P	$9.1 \times 10^{-15}$	$1.0 \times 10^{-6}$
<sup>28</sup> Al	$7.0 \times 10^{-13}$	$8.1 \times 10^{-5}$
<sup>22</sup> Na	$5.6 \times 10^{-17}$	$6.3 \times 10^{-9}$
<sup>15</sup> O	$6.7 \times 10^{-9}$	$7.4 \times 10^{-1}$
<sup>14</sup> O	$2.8 \times 10^{-10}$	$3.2 \times 10^{-2}$
<sup>13</sup> N	$1.6 \times 10^{-9}$	$1.8 \times 10^{-1}$
<sup>11</sup> C	$7.0 \times 10^{-10}$	$8.1 \times 10^{-2}$
<sup>7</sup> Be	$1.9 \times 10^{-13}$	$2.1 \times 10^{-5}$
<sup>3</sup> H	$7.7 \times 10^{-15}$	$8.8 \times 10^{-7}$

Given these radionuclide quantities, the dose to the maximally exposed individual of the public has been estimated using the Clean Air Act Code CAP88-PC. The standard BNL site-specific model was utilized with 10-year average wind rose, temperature and precipitation and the most current, CY 2000, population data. The CAP88-PC model is designed to model continuous airborne radioactive emissions that occur over the course of a year. The radionuclides in Table 4.5.4.a were modeled as if they were released in this manner. Aluminum-28 and oxygen-14 are not included in the CAP88-PC radionuclide library and thus are not included in the model. However, the source terms and half-lives of these radionuclides are so small that their exclusion has no effect on the conclusions of the evaluation. Chlorine-39 and chlorine-38 were also not included because their effect has no effect on the conclusion.

Appendix 4 showed that the dose to the BNL site maximally exposed individual of the public at the northeastern site boundary is  $9.7 \times 10^{-6}$  mrem/yr.<sup>45</sup> This dose is six orders of magnitude below the 10 mrem/yr limit specified in 40CFR61, Subpart H, and a factor of ten-thousand times less than the 0.1 mrem/yr limit that triggers the NESHAPs permitting process. Therefore, no application for a permit was required for the Booster Applications Facility and continuous monitoring of the release point is not required.

Normally, the Target Room is ventilated continuously to reduce odors from the biological specimens. The ventilation system will maintain the radionuclide concentrations at insignificant values in the Target Room. If the ventilation is off and irradiations and entries are still made, the dose to an individual who spends an hour in the

<sup>45</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/BAF/BAFSADAppendix4.pdf>, Appendix 4, BAF SAD, G. Schreoder, Booster Applications Facility Facility/Process Radionuclide Evaluation, January 4, 2001.

Target Room would be a small fraction of a mrem. Thus, there are no significant hazards from loss of Target Room ventilation.

The materials used in construction of the Booster Applications Facility experimental areas are limited in number, the most important being iron, steel, copper, aluminum, concrete, oil and plastic. These metals and materials are generally not used in their pure form; that is, they have welds, or they are alloyed with other metals, or they are parts of beam-line components. Thus, irradiation produces a variety of radionuclides in any given item. Based on recent studies on the C-A radioactive waste stream, nuclides ranging in half-life from days to years are formed in these materials. Table 4.5.4.b is a summary of the dominant radionuclides produced in each material. Experience with these activated materials and radioactive waste streams at BNL accelerators and experiments, shows that the current administrative and work controls are adequate to minimize their hazards.

Table 4.5.4.b Radionuclides Predominantly Observed in the Waste Stream from High Energy Hadron Accelerator Operations

Irradiated Material	Radionuclides Observed in the Waste Stream
Plastic, Oil	$^7\text{Be}$ , $^{22}\text{Na}$ , $^{46}\text{Sc}$ , $^{54}\text{Mn}$ , $^{57}\text{Co}$ , $^{60}\text{Co}$ , $^{68}\text{Ga}$ , $^{88}\text{Zr}$ , $^{113}\text{Sn}$ , $^{124}\text{Sb}$ , $^{125}\text{Sb}$ , $^{133}\text{Ba}$ , $^{134}\text{Cs}$ , $^{207}\text{Bi}$
Concrete	$^7\text{Be}$ , $^{22}\text{Na}$ , $^{46}\text{Sc}$ , $^{54}\text{Mn}$ , $^{57}\text{Co}$ , $^{58}\text{Co}$ , $^{60}\text{Co}$ , $^{65}\text{Zn}$ , $^{110}\text{Ag}$ , $^{134}\text{Cs}$
Aluminum	$^7\text{Be}$ , $^{22}\text{Na}$ , $^{54}\text{Mn}$ , $^{57}\text{Co}$ , $^{58}\text{Co}$ , $^{60}\text{Co}$ , $^{65}\text{Zn}$ , $^{68}\text{Ga}$ , $^{95}\text{Nb}$ , $^{110}\text{Ag}$ , $^{133}\text{Ba}$ , $^{134}\text{Cs}$
Iron, Steel	$^7\text{Be}$ , $^{22}\text{Na}$ , $^{46}\text{Sc}$ , $^{54}\text{Mn}$ , $^{59}\text{Fe}$ , $^{56}\text{Co}$ , $^{57}\text{Co}$ , $^{60}\text{Co}$ , $^{65}\text{Zn}$ , $^{68}\text{Ga}$ , $^{75}\text{Se}$ , $^{95}\text{Nb}$ , $^{110}\text{Ag}$ , $^{113}\text{Sn}$ , $^{124}\text{Sb}$ , $^{125}\text{Sb}$ , $^{133}\text{Ba}$ , $^{134}\text{Cs}$ , $^{207}\text{Bi}$
Copper	$^7\text{Be}$ , $^{22}\text{Na}$ , $^{54}\text{Mn}$ , $^{57}\text{Co}$ , $^{58}\text{Co}$ , $^{60}\text{Co}$ , $^{65}\text{Zn}$ , $^{68}\text{Ga}$ , $^{110}\text{Ag}$ , $^{133}\text{Ba}$ , $^{134}\text{Cs}$

Radioactivity is also produced directly in the Booster Applications Facility closed primary cooling water systems. Experience indicates that  $^7\text{Be}$  and  $^3\text{H}$  are the two long-lived radionuclides that are produced. The estimates indicate mCi amounts of these longer-lived radionuclides will be produced annually. Operation of AGS primary cooling water systems causes much higher activities and volumes of activated cooling water. Handling AGS cooling water and responding to spills has shown that there is no significant hazard to workers. Current procedures and controls will assure that Booster Applications Facility primary cooling water will not be hazardous to workers. Tritium is always produced in conjunction with gamma emitters so a gamma detector is sufficient to monitor spilled primary water. In the event of an inadvertent release or spill, gamma radiation monitors in the sanitary waste system, the system which receives spilled activated cooling water, are designed to trigger the diversion of significant levels of radioactive water away from the BNL Sewage Treatment Plant and toward a lined hold-up pond for additional sampling and treatment. However, significant levels of activated primary water, significant enough to trigger the holdup process, are not anticipated to be produced due to normal operations.

In addition to direct activation of primary water, slight amounts of radioactivity that is induced in the magnets is picked up in this same cooling water due to corrosion. Current AGS systems have  $\mu\text{Ci}$  amounts of corrosion products such as  $^{54}\text{Mn}$ ,  $^{22}\text{Na}$  and

<sup>65</sup>Zn. On the other hand, activated cooling water is in closed re-circulated systems that are de-ionized, which greatly reduces the amount of dissolved corrosion products. Closed system or "contact" cooling water is monitored before discharge. The planned release of cooling water follows receipt of analytical data showing acceptable levels for all radionuclides as long as the requirements of the State Pollution Discharge Elimination System Permit (SPDES) are satisfied. Additionally, the metals content is monitored in both "contact" and "secondary" cooling waters.

Primary cooling water will briefly contain small amounts of short-lived radio-gases that are isotopes of nitrogen and oxygen. The minor external radiation hazard near the contact cooling water piping from circulating these radio-gases is momentary, lasting 5 to 10 minutes after shutdown of the beam. The most radioactivity in cooling water, other than dissolved short-lived radio-gases, is from tritium. The current level of tritium in the Booster magnet cooling water, which has been building up for several years, is  $2.8 \times 10^5$  pCi/L, which is about 14 times greater than the Drinking Water Standard. The annual Booster accelerated particles averaged over the last few years is about  $2.0 \times 10^{20}$  GeV. Thus by ratio to annual BAF running,  $1.0 \times 10^{17}$  GeV, the tritium in cooling water would build up by about 150 pCi/L per year. This level would be at or below the minimum detectable level for routine tritium monitoring, at least during the first few years, and cooling water leaks would not be of concern with regard to spreading radioactive contamination. Other radionuclides in cooling water will be either too short-lived (minutes) or be removed by the BAF ion-exchange system and trapped in solid media.

Secondary water from the cooling towers, which is not radioactive, is discharged into recharge basins if the metals content is not greater than permitted.

Regarding hazards from activated animal waste; assume a sample receives a near lethal dose of 500 rad (5 Gy) from 1 GeV/nucleon iron ions. This corresponds to  $4 \times 10^8$  iron-ions for a 20 cm<sup>2</sup> beam-size, or  $2.3 \times 10^{10}$  nucleons at 1 GeV. See C-A OPM 9.1.11, Section 5.4, for dose to beam conversion functions. For soft tissues, water comprises about 80% of mass. Assume a sample is made of water, presents a 20 cm<sup>2</sup> area to the beam and is 20 cm long. Given a 30 mb cross-section for tritium production from high-energy nucleon-collisions with oxygen, the total tritium created in a sample from a 500 rad dose is 22 pCi. Given that water has about 200 to 400 pCi/L of naturally occurring tritium, the activated excreta of animals is not expected to be measurable nor is it a significant radioactive hazard.

#### 4.5.5. Fire Hazards

The primary combustible loading in the Booster Applications Facility consists of magnets, power and control cables, and beam diagnostic equipment located in the Tunnel and the Power Supply Building. None of the materials is highly flammable, and with the possible exception of small amounts of control cable, all are expected to self-extinguish upon the de-energizing of electric power. Small amounts of flammable materials, in quantities of less than 1 quart each, will be used in the Support Building. The buildings, tunnel and cooling towers are all constructed of non-combustible materials.

Due to a system for diversion of radioactive liquid effluent to a hold-up pond, there are no environmental impacts due to release of contaminated water from the fire

protection water system. Water sprayed on radioactive equipment may become slightly contaminated but would enter the sanitary system and be monitored before release. There are no significant amounts of combustible activated materials in the tunnel or beam lines and no significant radioactive particles would be present in smoke. Thus, there is no significant environmental hazard from a fire at the Booster Applications Facility.

#### 4.6. Hazard Controls

The purpose of this section is to briefly summarize the various system features and administrative programs that help to control hazards or the minimize risk of various hazards.

##### 4.6.1. Radiation Protection

The significant hazard at the Booster Applications Facility is ionizing radiation, and operations are planned to be within DOE dose guidelines. The Department uses a graduated system of shields, fences or barriers, locked gates, interlocks and procedures to match access restrictions with potential radiation hazards that satisfies both the BNL and DOE requirements.

Although the Laboratory site is a limited access site, service personnel from off-site or BNL non-radiation workers may work near the accelerators or may traverse the complex. The Laboratory policy is to restrict the dose to 25 mrem per year to such personnel. The C-A Department adheres to this policy by using shielding and radiation monitoring devices that prevent radiation levels from exceeding set points.

Shielding for Booster Applications Facility is also designed to permit access by appropriately trained personnel to areas adjacent to the beam enclosures and Target Room even with nominal inadvertent beam loss. In locations where the losses are expected to be greater, such as outside the shielding near collimators or the beam stop, physical barriers such as fences are used to control access and minimize exposures. Depending on the area classification, these barriers may be locked and/or posted as Controlled Area or Radiation Area.

There is the potential of significant residual activity in several locations, which are collimators, injection region, and beam dump. To work near these locations, movable shielding may be brought into place using the remote capabilities such as a crane or a fork truck. This minimizes the potential integrated person-dose for work done within the beam enclosure.

##### 4.6.1.1. Permanent Shielding and ALARA Dose

Shielding design analyses were performed for all sections of the Booster Applications Facility, and ALARA was integrated into the overall facility design. Soon after beam is available, studies will be conducted in order to verify the design and to optimize shielding, as needed, to help achieve an ALARA dose to facility personnel and facility users. Extensive radiation surveys of normal operations, as well as low-intensity simulated, credible beam faults, will be conducted during commissioning and initial operations. These surveys will provide assurance and verification of the adequacy of the

shielding and access controls. It is noted that the permanent shielding and access controls are configured to support the BNL RadCon Manual dose limit requirements, and are further enhanced to support the BNL RadCon Manual ALARA considerations.

The shield was planned with ALARA in mind such that, during normal operations, the dose rate on accessible outside surfaces of the shield is planned to be less than 0.25 mrem/h in areas under access control. Areas under access control at the Booster Applications Facility are all designated Controlled Areas or radiological areas as defined in the BNL RadCon Manual. The design of 0.25 mrem/hr is a guideline based on the actual ALARA design objective of less than 500 mrem per year. That is, assuming 100% occupancy at the shield face, a 2000-hour per year residence time yields an acceptable ALARA design objective of 500 mrem. The 500 mrem per year ALARA design objective is one half the design objective stated in 10CFR835 § 835.1002 (b).

Since there are many ways to control access and residence time by area designation, training, signage and work planning and since there is a decrease of dose rate with distance from the shield face, significantly higher shield face dose rates are often acceptable. Therefore, in the following subsections, the shields are evaluated in terms of the guideline of 0.25 mrem/h, and instances where higher values may be acceptable are mentioned to indicate where area designations will play a major role in minimizing radiation exposures.

#### 4.6.1.2. Permanent Shielding Materials

The permanent bulk shielding materials for the Booster Applications Facility are primarily materials used at existing BNL accelerator facilities. For example, concrete, iron and earth provide protection for personnel outside the Booster Applications Facility tunnel and Target Room. In addition, as discussed later in this analysis, the transport line and the beam dump berms are covered with caps to prevent leaching of soil activation products, tritium and sodium-22, from contaminating the groundwater. In addition to the materials mentioned above, paraffin, borated paraffin, polyethylene, borated polyethylene and lead may be used for local shielding and in special circumstances. Shielding configuration is closely controlled and may not be changed without review and approval of the C-A Radiation Safety Committee (RSC).

#### 4.6.1.3. Radiation Detection and Radiation Interlocks

At locations external and/or adjacent to beam enclosures where unlikely but possible beam loss may occur, the use of hard-wired, fail-safe interlocking radiation monitors is planned. This technique is standard practice at DOE accelerator facilities to maintain radiological-area classification compliance by providing a robust and rapid beam inhibit if any monitor exceeds a preset interlock limit. The Booster Applications Facility will treat these radiation monitors as part of the QA level A1 safety-significant access-control-system for personnel protection.

Interlocking radiation monitors are to be calibrated annually. These radiation monitors have been dubbed 'Chipmunks.' They are tissue-equivalent ionization chambers that measure dose equivalent rate, in mrem per hour, from pulsed, mixed-field neutron and gamma radiation. Chipmunks are used as area-radiation monitors for

personnel protection and are located throughout the facility in accessible areas. Chipmunks are used to interlock the accelerator beams should radiation levels exceed limits defined by the C-A Radiation Safety Committee. The operation of Chipmunks with interlocking capability is fail-safe. Loss of power results in beam off for interlocked Chipmunks, and/or an alarm in the Main Control Room in Building 911, a control room that is manned around-the-clock during operations. Additionally, the Chipmunk uses a built-in keep-alive radiation source to monitor for failures. Such a failure will trigger an alarm in the Main Control Room and/or an interlock when appropriate.

The interlock system is hard-wired and uses relay logic and PLCs to activate or deactivate a device such as a beam stop or magnet power supply to prevent beam from entering the fault area when a fault condition is detected. The portion of the system that is PLC based is patterned after the system used at RHIC. This system is monitored by an independent computer, and the fault condition is logged.

Fixed-location area-radiation monitors such as Chipmunks also provide real-time dose information at various locations along the beam path and in the target and support buildings. This dose rate data is logged every few minutes and stored on computers. General locations have been selected for the real-time monitors; exact locations will be determined based on beam-loss tests conducted during the commissioning phase and on subsequent radiation surveys during operation. Final area radiation monitoring instrument locations will be approved by the Radiation Safety Committee.

Additional area monitors may be used to assess the long-term integrated dose in areas accessible to the public and other individuals not wearing personnel dosimeters. Thermo-luminescent dosimeters (TLDs) identical to those worn by radiation workers will be mounted in locations approved by the Radiation Safety Committee for this purpose. The dose recorded by these TLDs will be indicative of the exposure of a person spending full time at that location. Neutron dosimeters, if their use is indicated for this purpose, will be attached to phantoms to simulate use by personnel.

#### 4.6.1.4. Portable Radiation Monitors

Portable radiation detection instruments will be used by Radiological Control Technicians (RCTs) and, potentially, other trained and approved C-A personnel, to measure the radiation fields in occupied areas during commissioning and periodically during normal operations. These measurements will be used to establish and confirm area radiological postings. Instruments used for this purpose will be appropriate for the type and energy of the expected radiation, and will be calibrated in accordance with requirements.

#### 4.6.1.5. Frisking Instruments

Experience at the AGS with virtually identical beams and identical NASA experiments have shown that contamination is not expected at Booster Applications Facility. However, routine contamination surveys will be conducted to verify that contamination is not a problem. Instruments used to frisk personnel who are exiting posted areas that might contain removable contamination will be used as appropriate.

#### 4.6.1.6. Personnel Dosimetry

All radiation workers will wear appropriate TLDs and self-reading dosimeters as required by the BNL Radiation Control Manual while working in areas posted for radiation hazards. Dosimeters will be exchanged on a regular basis and processed by a DOELAP-accredited laboratory. Records of the doses recorded by these dosimeters will be retained, and these records will be made available to the monitored individuals.

#### 4.6.1.7. Access Controls Systems

The radiation security system will use the same design as existing access controls at C-A facilities that have been in operation for nearly 40 years. The C-A Department has classified the security system as QA level A1 according to the C-A QA plan, but the Department allows certain components to have a lower classification because failure is to a safe state or critical parts are redundant. The Access Controls Group installs industrial grade components only. This Group labels parts that pass incoming tests as A1 or A2 and places labeled parts in controlled storage areas. The Group maintains documentation for these acceptance tests.

The basic design principles of the access control system are:

- Either the beam is disabled or the related security area is secured.
- Only wires, switches, relays, PLCs and active fail-safe devices, such as Chipmunks, are used in the critical circuits of the system.
- The de-energized state of the relay is the interlock status; that is, the system is fail-safe.
- Areas where radiation levels can be greater than 50 rem/h require redundancy in disabling the beam and in securing the radiation area.
- If a beam fails to be disabled as required by the state of its related security area, then the upstream beam would be disabled; that is, the system has backup or reach-back.

Very High Radiation Areas are those areas that enclose primary beam such as the Booster Applications Facility beam line and Target Room. Very High Radiation Area hardware requirements comply with the BNL RadCon Manual. The C-A Radiation Safety Committee requires: 1) locked gates with two independent interlock systems, 2) fail safe and redundant radiation monitors or other sensing devices, 3) indicators of status at the facility in the Main Control Room, 4) warning of status change, and 5) emergency stop devices within potential Very High Radiation Areas.

The C-A Radiation Safety Committee reviews interlock systems for compliance with requirements in the BNL RadCon Manual, Standards Based Management System requirements and C-A Operations Procedure Manual procedures. A Representative of the BNL Radiological Controls Division is a member of the C-A Radiation Safety Committee. The C-A Radiation Safety Committee defines the design objectives of the security system and approves the logic diagrams for relay-based circuits and state tables for PLC-based circuits. Cognizant engineers sign-off on wiring diagrams and the C-A Chief Electrical Engineer approves each diagram. The C-A Access Controls Group maintains design documentation.

The Access Controls Group conducts a complete functional check of all security system components at an interval required by the BNL Radiological Control Manual. In

the checkout, the Access Controls Group checks the status of each door-switch on a gate, and each crash switch in the circuit. They check the interlocks and the off conditions for all security-related power-supplies to magnets, magnets that may act as beam switches, and for all security-related beam-stops. They check every component in a security circuit. As they test, they fill-out, initial and date the security system test-sheets obtained from the C-A Operations Procedure Manual. Test records are maintained as required by the C-A Operations Procedure Manual.

#### 4.6.2. Electrical Safety

The requirements for electrical safety are given in detail in the BNL Standards Based Management System and the C-A Operations Procedures Manual. Electrical bus work is covered to reduce/prevent electrical hazards in the power supply areas. In beam enclosure areas, exposed conductors will not be present and magnet buss will be covered. The Main Control Room will lock out all power supplies that power devices inside a beam enclosure whenever the area is placed in Restricted Access mode. In Controlled Access mode, even though the magnets will not be powered, the power supplies will not be locked out. Workers are trained to assume that magnets are powered in all cases and to treat them accordingly. In cases where workers are required to work on or near a specific magnet during Controlled Access or Restricted Access, the magnet power supply will be locked out and tagged out by the worker.

In some cases, it will be necessary to work near magnetic elements while powered. Appropriate control over access during this mode is maintained by the Operations Coordinator. Work planning, Working Hot Permits and training requirements for entrants under these circumstances address concerns for inadvertent contact with powered conductors and exposure to magnetic fields.

#### 4.6.3. Lockout/Tagout

Lockout/tagout procedures are specified in the C-A Operations Procedure Manual. All workers will be required to train in lockout/tagout procedures at a level consistent with their position. Where electrical hazards could be present to C-A personnel working in an area, lockout/tagout procedures shall be executed only by trained and authorized personnel.

#### 4.6.4. Safety Reviews and Committees

Standing safety committees shall be utilized throughout design, construction, commissioning and operation to focus expertise on safety, environmental protection, pollution prevention and to help maintain configuration control. See Chapter 3, Section 3.4.3.10.

#### 4.6.5. Training

Worker training and qualification is an important part of the overall ESH plan for C-A Department. Training and qualification of workers is described in the Operations

Procedures Manual and the required training for individuals is defined in the Brookhaven Training Management System (BTMS). All Booster Applications Facility personnel and experimenters will require an appropriate level of training to ensure their familiarity with possible hazards and emergency conditions.

Workers will be trained in radiation and conventional safety procedures at a level consistent with their positions. The number and type of training sessions/modules will be assigned using a graded approach commensurate with the staff members responsibilities, work areas, level of access, etc. An up-to-date record of worker training will be kept in the BTMS database. Radiation worker access will only be allowed if adequate training is documented, except in cases of emergency. Training procedures and course documentation will be reviewed and updated periodically.

#### 4.6.6. Personal Protective Equipment

Special clothing will be used to protect workers who are exposed to the various hazardous materials found at the Booster Applications Facility, including chemicals and radiation. The clothing for a particular application will be selected considering the expected hazards; a variety of types of clothing will likely be needed to meet all hazards. There are no predicted hazards that are unique to the Booster Applications Facility, and experience gained at other C-A facilities will be applied to ensure the adequacy of protective clothing in a particular application.

Respiratory protection will be provided for workers who might otherwise be exposed to unacceptable levels of airborne hazardous materials, including chemicals and radioactive materials. Respiratory protection will be selected, used and maintained per OSHA 29CFR1910.134 and BNL Respiratory Protection Procedures.

#### 4.6.7. Control of Radiation and Radioactive Materials

##### 4.6.7.1. Control of Direct Radiation

Shielding will be used to reduce radiation levels in occupied areas to acceptable levels. The C-A Department's shielding policy is given in [Appendix 10](#). Potential access points into areas where personnel are prohibited during operations will be controlled by the Access Control System. Areas with elevated radiation levels that are accessible to personnel will be posted in accordance with BNL RadCon Manual requirements, and individuals will be appropriately trained before being granted unescorted access to Controlled or radiological areas.

Individuals entering areas posted for direct radiation will have appropriate dosimetry and will have written authorization to enter into and perform work in radiological areas. Periodic radiological surveys during operations will confirm that postings are appropriate. Exposure of personnel to radiation will be controlled through the combination of exclusion from areas with immediately hazardous radiation levels and postings that inform workers of hazards in accessible areas.

#### 4.6.7.2. Control of Radioactive Materials and Sources

When the beam is turned off, the remaining radiation hazard comes from activated material and sources. Activated material may be a direct radiation hazard, and may have removable contamination. All known or potentially activated items will be treated as radioactive material and handled in accordance with BNL RadCon Manual requirements. Unlabeled radioactive material that is accessible to personnel will be in an appropriately posted radiological area. Suspect radioactive material will be surveyed by a qualified person before release and then controlled in accordance with the survey results. Process knowledge may also be used to certify items being removed from radiological areas as being free of radioactivity. Known radioactive materials will be appropriately labeled before removal from an area that is posted and controlled. Radioactive items with removable contamination on accessible surfaces will be packaged before removal from posted radiological areas. Workers whose job assignment involves working with radioactive materials will receive documented training as radiological workers. Radioactive sources below accountable-activity-limits will be treated as radioactive material. Accountable sealed radioactive sources will be controlled, labeled and handled in accordance with the BNL RadCon Manual and the C-A Operations Procedure Manual. Accountable sealed radioactive sources that are in regular use will be inventoried and leak-tested every six months.

#### 4.6.8. Control and Use of Hazardous Materials

The BNL Chemical Management System is designed to ensure that workers are informed about the chemical hazards in their workplace. The Chemical Management System is maintained to comply with OSHA and EPA regulations concerning hazardous chemical communications. This program includes provisions for policy, training, monitoring exposure limits, handling, storing, labeling and equipment design, as they apply to hazardous materials. Inclusive in the hazardous material protection program will be: procurement, usage, storing, inventory, access to the hazardous materials, as well as housekeeping and chemical hygiene inspections of the Booster Applications Facility Experimental Support Building. All BNL general employees receive appropriate general Hazard Communication training. Standards for general hazardous materials communication and for special materials, such as beryllium, mercury and biological materials are specified by the BNL Standards Based Management System. Training to these standards is provided, and the training program records are maintained on the BNL BTMS. Booster Applications Facility employees working in areas with a potential for exposure to hazardous chemicals receive appropriate job-specific training at the time of initial assignment and whenever a new hazard is introduced into the work area. A comprehensive listing of all Materials Safety Data Sheets for the chemicals used at the Booster Applications Facility site is available on the BNL web or equivalent. The system of work controls, which is part of the BNL Integrated Safety Management System, requires enhanced work planning for work with certain hazardous materials; for example, beryllium. The enhanced work planning will assure that adequate hazard controls and completion of required training are in place before work with hazardous materials can begin.

The use of flammable liquids will be minimal. The anticipated use is less than 1 quart in each laboratory space as a solvent. Any use of flammable liquids follows BNL ES&H Standards / SBMS requirements. Propane for Bunsen burners is either stored external to the Support Laboratory building or contained within a continuously vented cabinet, which discharges to the outside.

#### 4.6.9. Significant Environmental Aspects and Impacts

In support of Brookhaven National Laboratory's broad mission of providing excellent science and advanced technology in a safe, environmentally responsible manner, the Collider-Accelerator Department is committed to excellence in environmental responsibility and safety in all C-A Department operations.

To provide excellent science and advanced technology in a safe and environmentally responsible manner the Collider-Accelerator has, over the past decade, continuously reviewed the aspects of its operations in an effort to identify and accomplish waste minimization and pollution prevention opportunities. This process began in 1988 with the development of formal environmental design guides and a design review process. More recently, this effort has resulted in a further formalization of its processes under the guidelines of ISO 14001, the BNL ISO 14001 "Plus" Environmental Management System Manual, and SBMS subject areas governing ISO 14001 implementation. Based on the aspect identification and analysis process in the Subject Area, Identification of Significant Environmental Aspects and Impacts, the following aspects are significant to the Booster Applications Facility activities:

- Regulated Industrial Waste
- Hazardous Waste
- Radioactive Waste
- Atmospheric Discharge
- Liquid Effluents
- Storage/Use Of Chemicals or Radioactive Material
- Soil Activation
- Water Consumption
- Power Consumption

The environmental policy as set forth by Brookhaven National Laboratory in the Environmental Stewardship Policy is the foundation on which the C-A Department manages significant environmental aspects and impacts. The formal management program is called the C-A Environmental Management System. The Environmental Management System consists of the following elements, the details of which may be found in the [C-A Operations Procedure Manual](#):<sup>46</sup>

- Environmental Policy
- Planning
- Environmental Aspects and Impacts
- System for Determining Legal and Other Requirements
- System for Defining Objectives and Targets

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<sup>46</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch01/01-10-02.PDF> Environmental Management Program Description

- Environmental Management Programs
- Implementation and Operation
- Structure and Responsibility
- Training, Awareness, and Competence
- Communication
- Environmental Management System Documentation
- Document Control
- Operational Control
- Emergency Preparedness and Response
- Checking and Corrective Action
- Monitoring and Measurement
- Nonconformance and Corrective and Preventive Action
- Records Management
- Environmental Management System Audit
- Management Review

The requirement for a process evaluation is listed in C-A OPM Chapter 13. Waste streams will be reviewed by the ECR and a process evaluation denoting all material inputs and outputs for the BAF will be performed before commissioning the facility for operations.

#### 4.6.10. Hazard Reduction Associated With Waste Generation and Handling

Hazards associated with handling, packaging, treating and disposing of wastes generated during operation and modification of the facility are reduced when the generation of these wastes is minimized via pollution prevention (P2) techniques. The BNL approach to P2 associated with the operation and modification of Booster Applications Facility is to address it during the design and construction phase. The objective is to minimize or eliminate the anticipated costs associated with hazardous and mixed waste generation as well as the treatment and disposal of wastes and the consumption of resources in all life cycle phases: construction, operation, closure and decommissioning. Dollars spent during the design phases will provide for significantly reduced total costs over the life of the facility thus making more funds available for science. The following are the main objectives of the BNL P2 program:

- Minimize the amount of hazardous, radioactive and mixed wastes that are generated.
- Minimize the cost of waste management.
- Comply with federal, state and local laws, executive orders and DOE orders.

The Collider-Accelerator Department has implemented a P2 program as part of its commitment to comply with the Environmental Management System and ISO 14001. C-A facilities are registered to the ISO standard by a third party registrar. A number of lessons learned from other BNL operations are incorporated into C-A operations. Modifications to C-A operations have helped minimize hazards and costs associated with the generation of waste streams.

#### 4.6.11. Fire Detection, Egress, Suppression and Response

In general the basis of design for fire detection, egress, suppression and response have been determined in the fire hazard analysis (FHA) in [Appendix 8](#). The Booster Applications Facility complies with DOE fire protection guidelines as well as NFPA's. The system is integrated with the site-wide system and is comprised of an automatic fire detection and suppression system that includes automatic wet-pipe fire suppression and rapid response capability coverage by the BNL Fire Department. Sprinklers are provided at the building ceiling or roof levels, intermediate levels and at or within enclosures, as required. Because of the low flammability of the magnets, power and control cables and beam diagnostic equipment in the tunnel, the tunnel does not have an automatic fire suppression system. The tunnel has a fire standpipe. Manual and automatic fire detection and alarm initiation devices are installed throughout the facility. Where needed, smoke and/or heat detection devices are supplemented with pressure sensitive sensors, combustible gas detectors or other advance detection devices. The appropriate portable fire extinguishers are provided for manual fire fighting efforts. Booster Applications Facility fire alarms are alarmed at the BNL Fire Department (Building 599), which is continuously manned and will respond to every fire alarm. This will put additional professional fire fighting resources into action within a short period. Roadway around the facility helps protect it from surrounding wildfires. The building roofs are non-combustible metal and do not ignite from burning ash from brush fires.

The BAF tunnel is joined to the Booster tunnel via a penetration that allows for transport of the beam in a vacuum tube to the BAF tunnel. This transfer line lacks combustibles and cannot convey a fire from tunnel to the other. While not a firewall, this arrangement provides a physical barrier that isolates the Booster and BAF.

The means of egress for occupancies is in accordance with NFPA 101. A tunnel exhaust fan (nominal 17,000 cfm) is located at the tunnel midpoint for rapid smoke removal. The fan is not required by code but can be manually started while fighting a fire in the windowless tunnel.

#### 4.7. Routine Credible Failures

Routine credible challenges to controls associated with worker and experimenter protection and with environmental protection are further detailed in [Appendix 9](#).

Beam losses in the Booster Applications Facility enclosures are sufficiently attenuated by the bulk shielding for expected routine operation. Adequate shielding is provided to meet requirements established by the Laboratory for permissible exposure to radiation workers and to members of the public during normal machine operations. Present shielding designs reduce all normal radiation levels to well below the DOE ALARA guidelines.

Exposure to nearby facilities is less than 25 mrem per year and much less than 5 mrem per year at the site boundary, which are the Laboratory guidelines for radiation exposure for nearby facilities and the site boundary, respectively. Radiation exposure to maintenance workers is reduced through the design of equipment to simplify maintenance and the selection of materials to minimize failures. In particular, equipment at high loss points such as targets receive detailed examination to assure that radiation

exposure received in passing and during the maintenance of these components is kept as low as reasonably achievable. Through such reviews, it is reasonable to expect that maintenance activities be controlled to maintain radiation exposures well within the DOE annual limits, limits that are 5 to 20 times higher than the ALARA guidelines.

There are no gaseous, liquid or dispersible quantities of radioactive materials, except for the radioactivity induced in magnet cooling water. In primary beam-line areas where the cooling water might escape confinement, e.g., a hose break, water detection mats underneath the magnets alarm and alert the watch personnel. Watch personnel are trained to confine, clean up and report water spills to management. Experience indicates that up to several hundred gallons may leak onto the concrete floor. Spilled water is sampled before release to the appropriate waste stream. No off-site threats to the public are anticipated.

#### 4.8. Maximum Credible Accidents

This section describes the bounding analysis scenarios for credible Booster Applications Facility accidents.

##### 4.8.1. Maximum Credible Beam Fault

Not all protons will be stopped at the targets or at well-defined loss points; some may be lost during transport. The design goal of no more than 20 mrem per full-fault event is adhered to in the design of shielding and radiation monitoring systems. Typically, the shielding on the transport lines allow these areas to be designated no more than a "High Radiation Area" during a full-fault event; that is, maximum hourly dose rate during a fault is less than 5000 mrem in 1 hour. These areas are further protected by radiation monitors, which are part of the access control system (ACS) that turns off the radiation source within 9 seconds of detecting a fault condition. Thus, the design guideline of no more than 20 mrem per event is met through a combination of shielding, radiation monitors and beam interlocks.

It is noted that placement of an array of chipmunk radiation monitors to catch a random fault anywhere along the beam line is not the intended strategy. Arbitrary losses will likely be detected, at least at some level, by one of three active chipmunks mentioned in Section 3.2.3. Experience at C-A shows that use of 1) thick shielding along the beam line and at the Target Room, 2) fences and barriers at the berm, 3) ALARA tuning procedures, 4) radiation alarms in MCR and procedures that call for response to radiation alarms are sufficient to protect personnel in locations not directly monitored by chipmunks.

A defocused or mis-steered beam during full intensity operation can cause a significant local loss of beam on a magnet. The worst-case beam loss event would be in the tunnel where the shield consists of 15 feet of earth compared to the 4 feet of concrete and 11 feet of earth at the Target Room. Using the Tesch method, a point fault of high-intensity protons in the tunnel would result in a dose of about 7 mrem at the shield surface. From [Appendix 3](#), the maximum, single event, non-routine point loss was taken to be  $1.5 \times 10^{14}$  3-GeV nucleons per second for 9 seconds on a magnet. The magnet

represents an addition of 1 foot of iron shielding to the 15 feet of earth. Nine seconds is the assumed response time of the ACS to interlock the beam and stop the fault.

We note that there are interlocks that would prevent high-intensity beam from entering Booster if the BAF critical devices are satisfied for protons; that is, a low-intensity mode for the Linac is required in order for BAF to have proton beam. Thus, the full-intensity proton beam-fault event is highly improbable. It is further noted that high-intensity protons may be allowed in Booster when BAF critical devices are satisfied for heavy-ion running if significant proton beam cannot be transferred by BAF extraction equipment operating in the heavy-ion mode. C-A RSC will review and approve the methods used to limit beam and determine if there are sufficient limits on the amount of beam that can be extracted.

Based on archival operating records, beam faults occur when magnet power supplies fail, or when beam-line components are misaligned and placed into the beam path. Operators in the Main Control Room detect the problem immediately due to alarms and due to the resultant interlock that turns the beam off. Operators are trained to investigate these events according to written procedures, correct the problem if appropriate, record the event for management review, and to discontinue operations if appropriate. Given the duration of these events, a few seconds or less, and the frequency of these events, several times during an annual running period, off-site radiation impact is much less than that from normal operations.

Due to the action of interlocking Chipmunks, the short-term duration of this fault causes insignificant impact either on the dose to personnel near the facility or the skyshine dose to nearby facilities or on soil activation. Part of the Booster Applications Facility commissioning process will require beam fault studies at low intensity to verify the adequacy of the shield.

Based on the system for formal design review by C-A Committees, formal training programs, formal operations procedures, formal quality assurance programs for equipment, and the extensive use of shielding and access controls, the probability of a "catastrophic" radiation exposure is extremely improbable; that is, the probability for this consequence cannot be distinguished from zero.

#### 4.8.2. Maximum Credible Fire

The objectives of presenting no threats to the public health and welfare or undue hazards to life from fire are satisfied. The Booster Applications Facility complies with the "Life Safety Code" (NFPA 101) and with the specific requirements of the Occupational Safety and Health Standards (CFR29, Part 1910) applicable to exits and fire protection.

Welding gases and flammable/explosive gases used in experiments are used and stored according to NFPA codes and standards applicable to experimental installations. Gases are stored in compressed gas cylinders that meet DOT specifications. Large quantities of gas are forbidden in experimental areas, and experimenters are limited to using 100 to 200 lb cylinders during running periods. No off-site threats to the public are expected should a cylinder fail.

Experiments are designed with an "improved risk" level of fire protection. The design requirements that were used are found in: 1) DOE Order 420.1, Facility Safety and

2) DOE Order 6430.1A, General Design Criteria. Experiments are fitted with fire detectors and fire protection systems where appropriate. Fires at experiments are expected to be extinguished by these protective systems. Combustible loading of the Booster Applications Facility primary beam line consists of magnets, power cables, control cables and beam diagnostic equipment. None of the materials are highly flammable, and with the possible exception of small amounts of control cable, all are expected to self extinguish upon de-energizing of electric power. Induced radioactivity is deeply entrapped in magnets and concrete shielding and is not dispersible in a fire. No off-site threats to the public are expected from a fire.

The personnel risks associated with the fire hazard are acceptable considering the type of building construction, the available exits, the fire detection systems, the fire alarm systems and the relative fire-safety of the components and wiring. Emergency power and lighting is available.

Travel distances to exits in the Booster Applications Facility Support Laboratory areas do not present a problem. In structures of low or ordinary hazard and in structures used for general or special industrial occupancy, NFPA 101 permits travel distances up to 120 m to the nearest exit if the following provisions are provided in full:

- Application is limited to one-story buildings only.
- Interior finish is limited to Class A or B materials per NFPA definitions.
- Emergency lighting is provided.
- Automatic sprinklers are provided in accordance with NFPA 101.
- Extinguishing system is supervised.
- Smoke and heat venting by engineered means or by building configuration are provided to ensure that personnel are not overtaken by spread of fire or smoke within 1.8 m of floor level before they have time to reach exits.

DOE has established limits of \$1,000,000 for a Maximum Possible Loss and \$250,000 for a Maximum Credible Loss mandating the installation of automatic suppression systems in locations where those limits are exceeded. The installation of sprinklers in the Booster Applications Facility Support Laboratory meets these criteria.

The Booster Applications Facility tunnel, Target Room and Power Supply Building do not have sprinklers. Since there is limited combustible loading in these areas and since the maximum fire-loss potential is less than \$1,000,000, the BNL Fire Protection Engineer determined that automatic fire suppression was not warranted ([Appendix 8](#)). The tunnel, Target Room and Power Supply Building are provided with automatic fire detection. Smoke and heat venting are in accordance with the Guide for Smoke and Heat Venting, NFPA 204. The maximum travel distance from any point within the tunnel to an exit is less than 120 m and therefore within the allowable distance. The smoke-exhaust system, emergency lighting, non-flammable construction, automatic fire-detection and low hazard fuel loading make the tunnel, Target Room and Power Supply Building acceptable.

No impairment of a vital DOE/NASA program from fire can occur because the maximum credible fire does not result in loss of use of the Booster Applications Facility for a period longer than the DOE criteria of three months. Replacement equipment exists and the time necessary for clean up and restoration is less than one month.

#### 4.8.3. Maximum Credible Electrical Damage

The Booster Applications Facility electrical systems and equipment are similar to those used at C-A facilities for many years. This statement does not minimize the inherent dangers; rather, it indicates that the technical personnel are experienced on accelerator circuits and devices. Additionally, they are qualified to work on the new systems. Every engineer, technician and electrician that is expected to work on the Booster Applications Facility equipment is adequately trained. The training includes an awareness of potential hazards and knowledge of appropriate safety procedures and emergency response plans. Training is documented and a list of authorized personnel is kept on a network electronic database (BTMS) and available to supervisors.

The C-A staff is familiar with the types of electrical hazards that relate to the accelerators and experimental areas. All reasonable safety features are installed in and on the electrical equipment. The groups that maintain, repair, test and operate the equipment have the knowledge, tools and experience to perform safely. Work planning, which includes electrical safety procedures, working hot permits and job safety analyses, is done to adhere to the safe practices mandated by OSHA and the BNL SBMS Subject Area on Electrical Safety. Continued training improves the safety margin. Thus, the potential risk for a serious electrical shock is minimized to levels currently accepted throughout the industry.

### 4.9. Risk Assessment To Workers, The Public And The Environment

#### 4.9.1. Radiation Risks

The routine radiation dose to workers is well below the DOE regulatory limits of 10CFR835. The range of doses received by C-A radiation workers in CY2000 is shown in Figure 4.9.1. Experience shows average exposure of C-A radiation workers is about 30 mrem per year. The dose to average C-A radiation worker is only a small fraction of the regulatory limit, and the increase in fatal cancer risk after a lifetime of radiation work, 50 years, is insignificant, 0.06%<sup>47</sup> compared to the naturally occurring fatal cancer rate of nearly 20%. The risks to the public are an extremely small fraction of worker risk; a factor of over 1,000,000 times smaller.

Worker doses, even including the maximum credible beam fault dose on a frequent basis, would not cause deterministic effects such as burns or tissue damage unless an individual were in the beam enclosure during operations. The Access Control System, which is categorized as Safety Significant, assures that such irradiations are not credible.

Ozone may be produced by ionizing radiation beams that pass through air. Ozone is an injurious gas at a relatively low concentration, a few ppm, and at a short exposure period, a few hours. Mild to moderate exposure produces upper respiratory tract and eye

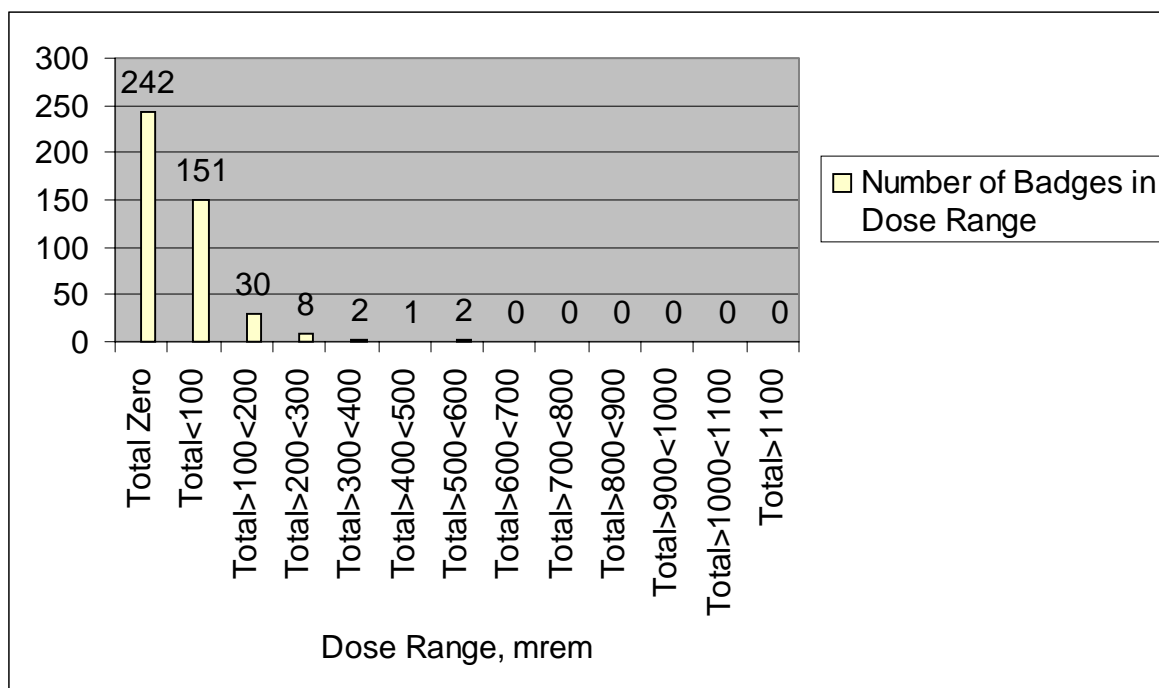
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<sup>47</sup> This assumes a risk coefficient of  $4 \times 10^{-4}$  per rem for workers from NCRP Report No. 115, Risk Estimates for Radiation Protection (p. 112) and a 50-year career at 5 rem per year.

irritations. More severe exposures may produce significant respiratory distress with dyspnea, cyanosis and pulmonary edema.<sup>48</sup>

The BAF Target Room allows particle beams to pass through up to 20 ft of air, although the experimental plan is to minimize the air gap where possible. Air emissions from the Target Room are vented to the outside at the rate of 535 CFM. The Target Room is 4000 ft<sup>3</sup>. Thus, the mean residence time of ozone in the Target Room is 7.5 minutes after the beam is off. If ventilation is off and if the maximum possible proton current from the Booster, 16.5 micro amps<sup>49</sup>, is passed inadvertently to the BAF Target Room for one hour, then 0.0043 ppm of ozone builds up. This hypothetical maximum fault level of ozone is 4% of the Threshold Limit Value (TLV), which is 0.1 ppm. Exposure at the TLV would not produce significant health effects. For the calculation of ozone concentration, it was assumed the collision stopping power for high-energy protons in air was 2.5 keV cm<sup>-1</sup> and the equation for ozone concentration in Appendix I of NCRP 51 was applicable.<sup>50, 51</sup> It is noted that the planned beam current for BAF is about 0.02% of the maximum possible current and that ventilation is normally on. Thus, the risk of significant exposure to ozone is extremely low.

Figure 4.9.1 Range of Radiation Worker Dose at C-A Department for CY2000



<sup>48</sup> Ellenhorn, M. J. and D. G. Barceloux, Medical Toxicology - Diagnosis and Treatment of Human Poisoning, New York, Elsevier Science Publishing Co., 1988.

<sup>49</sup> The maximum proton beam is 10<sup>14</sup> protons/second, Booster Final Safety Analysis Report, 1991.

<sup>50</sup> Stopping power for protons is given in the Appendix to ICRU 28, Basic Aspects of High Energy Particle Interactions and Radiation Dosimetry, International Commission on Radiation Measurements and Units, Washington, D.C., 20014, December 1978.

<sup>51</sup> Radiation Protection Guidelines for 0.1–100 MeV Particle Accelerator Facilities, National Council on Radiation Protection and Measurements, NCRP Report 51, Washington, D.C., 20014, December 1979.

#### 4.9.2. Infectious Microorganism Risks

Biological safety cabinets (BSCs) are the primary means of containment developed for working safely with infectious microorganisms. This equipment, which is located in cell rooms C1 and C2 of the Support Laboratories, is appropriate when any work is done with human-derived blood, body fluids or tissues where the presence of an infectious agent may be unknown. Class II Type A BSCs provide personnel, environmental and product protection. Airflow is drawn around the operator into the front grille of the cabinet, which provides personnel protection. In addition, the downward laminar flow of HEPA-filtered air provides product protection by minimizing the chance of cross-contamination along the work surface of the cabinet. Because cabinet air exhaust is passed through a certified exhaust HEPA filter, it is contaminant-free (environmental protection), and may be re-circulated back into the laboratory (Type A), which is the type of BSC employed at BAF cell rooms. CDC standards for BSC testing require an annual test, which includes annual efficiency tests as well as a smoke test and air velocity test. The BSC must maintain a minimum calculated or measured average inflow velocity of at least 75 linear feet per minute at the face opening of the cabinet.

#### 4.9.3. Environmental Risks

The only credible risk to the environment is groundwater contamination. This may be caused by a spill of radioactive cooling water from a failed pipe or hose or by a soil cap failure, which would allow rainwater to leach the contamination into the aquifer.

An extensive groundwater-monitoring program has been instituted to verify the effectiveness of soil caps and soil-cap maintenance procedures. In accordance with DOE Order 5400.1, General Environmental Protection, groundwater quality downgradient of the BAF target/beam stop area will be verified by periodic sampling of two groundwater surveillance wells (e.g., existing well 054-08 and new well AGS-44). Groundwater quality will also be verified downgradient of the Booster to BAF extraction point using two downgradient surveillance wells (e.g., existing wells 064-51 and 064-52). See Figure 4.9.3. In both areas, groundwater samples will be tested for tritium and sodium-22 to verify that the soil caps are effectively preventing rainwater infiltration of activated soil shielding. Sampling frequency for the wells will be defined in the annual BNL Environmental Monitoring Plan. The detection of unexpected levels of tritium and/or sodium-22 in groundwater will be evaluated in accordance with the BNL Groundwater Protection Contingency Plan.

There are no significant gaseous, liquid or dispersible quantities of radioactive materials, except for the radioactivity induced in magnet cooling water. Even though tritium levels in cooling water are less than the Drinking Water Standard, this water is doubly contained. In primary beam-line areas where the cooling water might escape confinement, e.g., a hose break, water detection mats underneath the magnets alarm and alert the watch personnel. Watch personnel are trained to confine, clean up and report water spills to management. Experience indicates that up to several hundred gallons may leak onto the concrete floor. Spilled water is sampled before release to the appropriate waste stream.

The operating procedures, the extensive groundwater monitoring program and the long delay times from spill to an offsite well location, which is decades, preclude the possibility of any worker or member of the public drinking radioactive groundwater.

There is no credible risk to the environment from airborne releases from the animal rooms (A1 and A2) in the BAF Support Laboratory, which are Biosafety Level 2. Ventilation is considered a secondary barrier for releases from Biosafety Level 2 facilities. Biosafety Level 2 requirements state, "There are no specific ventilation requirements. However, planning of new facilities should consider mechanical ventilation systems that provide an inward flow of air without re-circulation to spaces outside of the laboratory. If the laboratory has windows that open to the exterior, they are fitted with fly screens."

The animal laboratories have HEPA filters installed in the room exhaust and in the room re-circulation lines. The requirements for HEPA filtering of exhaust appear in Biosafety Level 3 requirements and even then are only required under certain conditions such as exhausting near occupied areas or ventilation intakes. From this point of view, HEPA testing would not be required since there is no Biosafety Level 2 requirement to have the filters installed. Although testing of HEPA exhaust is not mentioned specifically in the regulations (<http://www.cdc.gov/od/ohs/biosfty/bmbl4/bmbl4s3.htm>), a HEPA filter efficiency test is performed annually.

The room numbers, the number of hoods in the Support Laboratory, and a brief summary of the types of work done in each lab hood is maintained in a database for the laboratory. From a regulatory standpoint, ventilation and exhaust systems for laboratory operations; i.e., lab hoods, are exempt from New York State emission source permitting requirements.

**BROOKHAVEN**  
NATIONAL LABORATORY

Environmental Services  
Division

Environmental Surveillance  
Monitoring Well Locations  
Booster Applications Facility Area

**LEGEND**

- Monitoring well
- Buildings, Facilities
- AGS Facilities
- AGS Beam Line
- June 2000 Groundwater Table (ft AMSL)
- General Direction of Groundwater Flow June 2000

**SCALE**  
Meters  
0 10 20 30  
Feet  
0 100

JLH - 06/04/01  
home4ceram/facilities/templn\_bafa.mxd  
Graphics/Facilities/templn\_bafa.ai

#### 4.9.4. Fire Risks

Based on the extensive use of fire protection, the appropriate location of exits and the use of an emergency exhaust system, high or medium consequence levels are extremely unlikely. Thus, the risk is acceptable.

The maximum credible fire loss in the Booster Applications Facility primary beam line would be the loss of a moderate-size magnet with adjacent beam diagnostic equipment and cabling, about a one hundred thousand-dollar property loss. In experimental and Support Building areas, the fire loss is estimated to be less than several hundred thousand dollars worth of experimental equipment. Thus, the consequence level for loss of equipment is medium. Based on the use of non-flammable materials in construction and low fuel loading, fire is not likely in the life cycle of the Booster Applications Facility and the risk is acceptable.

#### 4.9.5. Electrical Risks

Based on the use of formal C-A electrical safety procedures, working hot permits and job safety analyses, high or medium consequence levels are extremely unlikely. Thus, the risk is acceptable.

#### 4.10. Professional Judgment Issues

The initial screening of Booster Applications Facility hazards was performed using qualitative engineering judgment. The C-A engineering, operating and safety staff has many years of experience with BNL accelerators and experiments. NASA experiments have been conducted using appropriate beams from the AGS to target caves in Building 912. This experience influenced the analyses of [Appendix 9](#).

[Appendix 3](#) describes the bases for conservative maximum hourly routine and faulted beam energy limits which have been used as the bases for the shielding and ALARA analyses. The judgment issues will be verified by fault studies.

#### 4.11. Methods Used in Evaluation of Radiological Hazards

Techniques employed in the evaluation of radiological hazards include the use of empirical formula,<sup>52,53</sup> and the Monte Carlo Programs MCNPX<sup>54</sup> and CASIM.<sup>55</sup> [A. J. Stevens](#) indicates CASIM has been used satisfactorily at BNL accelerators for many years at energies above 10 GeV, and has been extensively compared to MCNPX at

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<sup>52</sup> K. Tesch and H. Dinter, "Estimation of Radiation Fields at High Energy proton Accelerators," Radiation Protection Dosimetry, Vol. 15 No. 2 pp. 89-107 (1986).

<sup>53</sup> C. Distenfeld and R. Colvett, "Skyshine Considerations for Accelerator Shielding Design," Nucl. Sci. Eng. Vol. 26, p. 117 (1966).

<sup>54</sup> L. S. Waters, Ed., "MCNPX USER'S MANUAL," LANL Report TPO-E83-UG-X-0001, (1999). See also H.G. Hughes, R.E. Prael, R.C. Little, "MCNPX – The LAHET/MCNP Code Merger," X-Division Research Note, 4/22/97. The version number of the code used in this note is 2.1.5.

<sup>55</sup> A. Van Ginneken, "CASIM; Program to Simulate Hadron Cascades in Bulk Matter," Fermilab FN-272 (1975).

energies above 2 GeV.<sup>56</sup> CASIM cannot be used directly for low-energy neutron transport. It has also been found to overestimate neutron flux in the very forward direction.<sup>57</sup> MCNPX is probably the most widely used neutron transport Monte Carlo code. Several MCNPX calculations have shown excellent agreement with empirical labyrinth formula.<sup>58</sup>

Past measurements by [Stevens](#) at approximately 90° have been made in BNL soil. They show that Booster Applications Facility calculations are overestimates and should be regarded as upper limits.<sup>59</sup>

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<sup>56</sup> A. J. Stevens, "N-Shield, Description," BNL C-A Dept. ES&F Division Note 157 (2000). <http://server.ags.bnl.gov/lopresti/157.PDF>.

<sup>57</sup> See above reference. The CASIM estimates of soil activation in the dump region are in fact overestimates. Conversely, CASIM dramatically underestimates neutron flux in the backwards direction, but no such estimates exist in the Booster Applications Facility geometry.

<sup>58</sup> K. Goebel, G.R. Stevenson, J.T. Routi, and H.G. Vogt, "Evaluating Dose Rates Due to Neutron Leakage Through Access Tunnels of the SPS," CERN LABII-RA/Note/75-10 (1975).

<sup>59</sup> A.J. Stevens, "Summary of Fault Studies at RHIC." BNL C-A Dept ES&F Note 156 (2000). <http://server.ags.bnl.gov/lopresti/156.PDF>

## 5. Chapter Five, Booster Applications Facility Accelerator Safety Envelope (ASE)

### 5.1. Background

The Accelerator Safety Envelope (ASE) formally establishes the set of bounding conditions on engineered and administrative systems, within which the Collider-Accelerator Department proposes to operate the Booster Applications Facility. These bounding conditions are based on the safety analysis documented in Chapter 4 of the Safety Analysis Document (SAD) for the Booster Applications Facility. The ASE assures the validity of the basic set of assumptions used in the SAD safety analysis and ensures that the physical and administrative controls used to mitigate potential hazards are in place.

DOE requires adherence to the approved bounding conditions of the Accelerator Safety Envelope, because it is the authorization basis for all commissioning and operations activities. This chapter provides an overview of the development of the content of the Booster Applications Facility ASE. The actual ASE is a separate, controlled document that must be approved by DOE, whereas the SAD receives BNL approval since the Booster Applications Facility is a low-hazard facility. DOE approval is required for all changes to the ASE. As per BNL Subject Area requirements, a proposed draft ASE is submitted to the Laboratory's ESH Committee for review at the time the SAD is submitted.

To understand the appropriate level of information to include in the ASE, one must first understand the overall flow-down of information from the "highest" safety limits to the lowest machine operating procedures. This flow-down generally has four levels that provide a defense-in-depth to ensure the safe and environmentally sound operations of the Booster Applications Facility. The top two levels of this information are placed in the Accelerator Safety Envelope (ASE). The lower two levels are formally established in the [Collider-Accelerator Conduct of Operations documentation](#)<sup>60</sup> and [Operations Procedure Manual](#).<sup>61</sup>

The highest-level information, "Safety Envelope Limits," is documented in Section 2 of the ASE. There are two categories of these limits. One is the absolute limit that BNL places on its operations to ensure that the regulatory limits established to protect the environment, the public and staff and visitors are met.

The second level is the design/operating limits used as a basis for the Safety Analysis Document (SAD) hazard/safety analysis. This second level of information, "Experimental and Operational Limitations" is documented in Section 3 of the ASE. This section identifies the calculated limitations on critical operating parameters that, in conjunction with the specifically identified hazard control considerations established by the facility design, construction or experimental design constraints, ensure the Booster Applications Facility and its experimental operations will not exceed the corresponding Safety Envelope Limits or operational safety parameters as evaluated in the SAD. These parameters are derived from the safety analysis of the SAD.

The third and fourth levels of information may or may not be included in the ASE. The ASE has been developed primarily to define the important limits for operation

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<sup>60</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/conductofops.htm> C-A Conduct of Operations

<sup>61</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/index.htm> C-A Operations Procedure Manual

within the assumptions of the SAD hazard/safety analyses and to define operability requirements of safety-significant systems. The scope and content of the ASE have been limited to include only the most critical requirements in order to make the ASE more operationally useful for controlling the safety of the Booster Applications Facility. Because of this philosophy, the details of the third and fourth levels may only appear in the controlled operating procedures, which are examined during the Accelerator Readiness Review process. This information may consist of documented or measurable limits and corresponding controls necessary to establish an operational margin of "safety" that may be more conservative than that established in the ASE. This "operating margin" provides a defense-in-depth approach to ensuring that the Collider-Accelerator Department will operate the Booster Applications Facility well within "Experimental and Operational Limitations" agreed to by DOE in formally approving the ASE. These lower levels of information in the C-A OPM also include administrative program requirements such as industrial safety, environmental safety, waste management, pollution prevention, radiation protection practices, workplace hazardous materials monitoring, use of PPE, etc., that protect workers and the environment.

Compliance with operating limits and controls in the third and fourth levels of information is achieved through training of personnel and adherence to requirements in procedures. Examples of third level information may include limits designed into the machine itself, such as its maximum beam power, beam energy or beam intensity. A physical change to the machine would be needed to violate these parameters. Adherence to configuration control procedures prevents violations. Examples of the fourth level include authorizations that prohibit use of the accelerator unless certain conditions are met, such as a fully functional personnel protection system, or a fully functional fire protection system, or an authorization to release an effluent to the sanitary system. Other fourth-level examples include procedures to ensure that a certain number of fully trained operators are on-duty, or to ensure that the loss-monitor system is working to limit beam loss to a specific location.

## 5.2. Summary of ASE Content

The basic content of the ASE includes the following sections:

### Section 1: Introduction

The following items are included:

- General actions to be taken upon discovery of a violation of the Safety Envelope, including shutdown of the facility.
- A description, or reference, to the method used by the Department for change control of the ASE.

## Section 2: Safety Envelope Limits

This section contains two categories of limits: the absolute limits that BNL places on its operations to ensure the Collider-Accelerator Department meets regulatory limits established to protect the environment, public and staff/visitors; and the design/operating limits used as a basis for the Safety Analysis Document (SAD).

## Section 3: Experimental and Operational Limitations

This section identifies the measurable limitations on critical operating parameters that, in conjunction with the specifically identified hazard control considerations established by the facility design, construction, or experimental design constraints, ensure the accelerator or experimental operations will not exceed either the corresponding Safety Envelope Limits or operational safety parameters, as evaluated in the SAD. These parameters are derived from the safety analysis in Chapter 4 of the SAD.

## Section 4: Engineered Safety Systems Requiring Calibration, Testing, Maintenance, and Inspection

This section includes the identification of the systems and requirements for calibration, testing, maintenance, accuracy or inspection necessary to ensure the continued reliability of engineered safety systems that ensure the operational integrity of Section 3: Experimental and Operational Limitations. Requirements are consistent with established BNL Policies.

## Section 5: Administrative Controls

This section includes the administrative controls necessary to ensure the operational integrity of Section 3: Experimental and Operational Limitations. Included are minimum staffing level requirements, qualification and training requirements for operations, minimum operable equipment, work planning and control systems and environmental release mitigation measures.

## 6. Chapter Six, Quality Assurance

### 6.1. Program

The Collider-Accelerator (C-A) Department has adopted, in its entirety, the [BNL Quality Assurance Program](#). This QA Program describes how the various BNL management system processes and functions provide a management approach which conforms to the basic requirements defined in DOE Order 414.1A, Quality Assurance.

The quality program embodies the concept of the "graded approach," i.e., the selection and application of appropriate technical and administrative controls to work activities, equipment and items commensurate with the associated environment, safety and health risks and programmatic impact. The graded approach does not allow internal or external requirements to be ignored or waived, but does allow the degree of controls, verification, and documentation to be varied in meeting requirements based on environment, safety and health risks and programmatic issues.

The BNL QA Program is implemented within the C-A Department using C-A QA implementing procedures. These procedures supplement the BNL Standards Based Management System (SBMS) documents for those QA processes that are unique to the C-A Department. C-A QA procedures are developed by the C-A QA and maintained in the [C-A Operations Procedures Manual](#), Chapter 13.

The C-A QA philosophy of adopting the BNL Quality Program and developing departmental procedures for the implementation of quality processes within C-A ensures that complying with requirements will be an integral part of the design, procurement, fabrication, construction and operational phases of the Booster Application Facility (BAF).

A Quality Representative has been assigned to serve as a focal point to assist C-A management in implementing QA program requirements. The Quality Representative has the authority, unlimited access, both organizational and facility, as personnel safety and training allows, and the organizational freedom to: assist line managers in identifying potential and actual problems that could degrade the quality of a process/item or work performance, recommend corrective actions, and verify implementation of approved solutions. All C-A personnel have access to the Quality Representative for consultation and guidance in matters related to quality.

### 6.2. Personnel Training And Qualifications

The BNL [Training and Qualification Management System](#) within the Standards Based Management System (SBMS) supports C-A management's efforts to ensure personnel working on the Booster Application Facility are trained and qualified to carry out their assigned responsibilities. The BNL [Training and Qualification Management System](#) is implemented within the C-A Department with the [C-A Training and Qualification Plan of Agreement](#).<sup>62</sup>

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<sup>62</sup> <http://www.agshome.bnl.gov/AGS/Accel/SND/Training/trainplan.pdf> C-A Department Training and Qualifications Plan

### 6.3. Quality Improvement

The BNL Quality Management System, supplemented by C-A procedures, provides the requirements for identifying, documenting and dispositioning nonconformances and for establishing appropriate corrective and preventive actions that are based on identified causes. The BNL Quality Management System provides guidance for trending nonconformances to recognize recurring, generic or long-term problems.

The decision to initiate quality improvement is based upon an evaluation of the seriousness, and the adverse cost and schedule impact of the nonconformance relative to the cost and difficulty of its correction. In some cases, corrective action may not be feasible.

The C-A Self Assessment Program provides information on scientific, business and operational performance for C-A's management, staff, customers, stakeholders and regulators. Self-assessment also provides a mechanism for improving the rules that govern training and qualifications, documents and records, work process, design, procurement, inspection and testing, and the assessment process itself. The Self-Assessment program evaluates performance relative to critical outcomes and internal performance objectives in order to identify strengths and opportunities for improvements within the C-A Department.

### 6.4. Documents And Records

The [BNL Records Management System](#) and controlled document Subject Areas within SBMS, supplemented by C-A procedures, provide the requirements and guidance for the development, review, approval, control and maintenance of documents and records.

C-A documents encompass technical information or instructions that address important work tasks, and describe complex or hazardous operations. They include plans, and procedures, instructions, drawings, specifications, standards and reports.

C-A records are information of any kind and in any form, created, received and maintained as evidence of functions, policies, decisions, procedures, operations, or other activities performed within the Department. Records are retrievable for use in the evaluation of acceptability, and verification of compliance with requirements. C-A records are protected against damage, deterioration or loss.

### 6.5. Work Process

Work is performed employing processes deployed through the BNL SBMS. SBMS Subject Areas are used to implement BNL-wide practices for work performed. Subject Areas are developed in a manner that provide sufficient operating instructions for most activities. However, C-A management has determined that it is appropriate to develop internal procedures to supplement the SBMS Subject Areas. However, C-A procedures are bounded by the requirements established by the BNL Subject Areas.

Group leaders and technical supervisors are responsible for ensuring that employees under their supervision have appropriate job knowledge, skills, equipment and

resources necessary to accomplish their tasks. Where applicable, contractors and vendors are held to the same practices.

The Quality Management System, supplemented by C-A procedures, provides processes for identifying and controlling items and materials to ensure their proper use and maintenance to prevent damage, loss or deterioration.

C-A management has identified those processes requiring calibrated measuring and test equipment. Item identification and control requirements are specified, when necessary, in appropriate documents, e.g., drawings, specifications and instructions. Materials undergoing tests or inspections are controlled to avoid the commingling of acceptable items with items of unknown origin or history, thus avoiding inadvertent use.

C-A management delegates authority to all C-A personnel to “Stop Work” to avoid unsafe work practices.

## 6.6. Design

The C-A staff planned, developed, defined and controlled the design of the Booster Application Facility in a manner that assured the consistent achievement of the producibility, performance, safety, reliability, maintainability and availability objectives. Design planning established the milestones at which design criteria, standards, specifications, drawings and other design documents were prepared, reviewed, approved and released.

The design criteria defined the performance objectives, operating conditions, and requirements for safety, reliability, maintainability and availability, as well as the requirements for materials, fabrication, construction, and testing. Appropriate codes, standards and practices for materials, fabrication, construction, testing, and processes were defined in the design documentation. Where feasible, nationally recognized codes, standards and practices were used. When those were either overly restrictive, or fell short of defining the requirements, they were modified, supplemented, or replaced by BNL specifications.

Specifications, drawings and other design documents present verifiable engineering delineations in pictorial and/or descriptive language representations of parts, components or assemblies for the Booster Applications Facility. These documents were prepared, reviewed, approved and released in accordance with C-A procedures. Changes to these documents were processed in accordance with the C-A configuration management procedures.

## 6.7. Procurement

Personnel responsible for the design or performance of items or services to be purchased ensured that the procurement requirements of the purchase request were clear and complete. Using the graded approach, potential suppliers of critical, complex, or costly items or services were evaluated in accordance with predetermined criteria to ascertain that they had the capability to provide items or services that conformed with the technical and quality requirements of the procurement. The evaluation included a review of the supplier's history with BNL or other DOE facilities, or a pre-award survey of the

supplier's facility. C-A personnel ensured that the goods or services provided by the suppliers were acceptable for intended use.

#### 6.8. Inspection and Acceptance Testing

The BNL Quality Management System within the SBMS, supplemented by C-A procedures, provided processes for the inspection and acceptance testing of an item, service or process against established criteria and provided a means of determining acceptability. Based on the graded approach, the need and/or degree of inspection and acceptance testing was determined during the activity/item design stage. Inspection/test planning had as an objective the prompt detection of nonconformances that could adversely affect performance, safety, reliability, schedule or cost.

When required, acceptance and performance criteria were developed and documented for key, complex or critical inspection/test activities. If an item was nonconforming, it was identified to avoid its inadvertent use. These processes also specified how inspection and test status was indicated either on the item itself, or on documentation traceable to the item.

The BNL Calibration Subject Area, supplemented by C-A procedures, describes the calibration process for measuring and test equipment. C-A management identified appropriate equipment requiring calibration. The calibration status was readily discernible and associated calibration procedures, documentation, and records were prepared and maintained. Calibrated equipment was properly protected, handled and maintained to preclude damage that could invalidate its accuracy. Measuring and test equipment found out of calibration was identified and its impact evaluated.

#### 6.9. Management Assessment

The managers of the four C-A Divisions periodically evaluated or “self-assessed” the effectiveness of the C-A organization and presented their report to Department management. Through the C-A Self-Assessment Program, a regular, systematic evaluation process was established wherein C-A assesses internal management systems and processes used to make fact-based decisions. For example, see the [FY01 C-A Self-Assessment Plan](#). The C-A Self-Assessment Program includes such items as: performance measures; compliance checks; effectiveness evaluations; job assessments; surveys; and environment, safety and health walk-throughs. Strengths and opportunities for improvement were identified. Assessment results were documented and were fed back to managers, and provided valuable input into the business-planning process.

C-A's Environment Management System and associated activities undergo review by ISO-certifying bodies, EPA and State and County agencies. Together these elements provide comprehensive and objective information used by C-A management in establishing strategic direction and improving environmental performance.

#### 6.10. Independent Assessment

Using the graded approach, C-A Management periodically evaluated the implementation of the BNL Management Systems, SBMS Subject Areas and C-A

specific processes. This was done through reviews, assessments and/or other formal means. The C-A QA Group performed these assessments. They included an evaluation of the safety and quality cultures in terms of the adequacy and effectiveness of the management structure, which included, but was not limited to, environment, safety and health, quality, conduct of operations, and training requirements.

Individuals verifying these activities had sufficient authority to access work area, and organizational freedom to accomplish the following: identify problems, initiate, recommend, or provide solutions to problems through designated channels, and verify implementation of solutions.

All assessments were planned and conducted using established criteria. The type and frequency of these assessments were based on the status, complexity and importance of the work or process being assessed. The results were documented, non-conformances and recommendations identified and presented to C-A Department management. The Department developed corrective actions to promote improvement. Actions were tracked by line management to assure closure. Those conducting independent assessments were technically qualified and knowledgeable in the areas assessed and were independent from the activities they assessed. Where necessary, subject matter experts were involved in the assessments to give insight into a particular area.

In addition, peer review is a process used at C-A by which the quality, productivity and relevance of science and technology programs is monitored and evaluated. In operational and environment, safety and health arenas, peer review was used to evaluate and independently verify engineering design and operational implementation.

## 7. Chapter Seven, Decommissioning Plan

### 7.1. Introduction

The objective of the BAF decommissioning plan, which will be developed near the end of the BAF operating lifetime, will be to determine the hazards and risks posed by decommissioning of the BAF facility at the end of its operating life and to plan the activities required to complete the decommissioning. Ensuring the safety of the workers, protecting the public and the environment and complying with applicable state and Federal regulations are of utmost importance in preparing the Plan. Management of the operating waste, or other hazardous materials that might remain in the facility after shutdown, as well as the waste generated during the decommissioning activities are key to conducting safe decommissioning. Therefore, an approach that accurately identifies the types and quantities of these materials, thereby establishing the facility baseline, is an important aspect of the decommissioning planning.

Another aspect of the decommissioning plan will be the determination of the final site configuration, or end-point, in which the facility, or site, will be left. Determining the desired product, as well as the risks present, are essential to planning the decommissioning. The preferred decommissioning alternative is Greenfield condition but the following four alternatives should be evaluated for the decommissioning plan, 1) re-use for a similar function; 2) safe storage; 3) Brownfield condition; 4) Greenfield condition. It is assumed that institutional control will remain in place under Federal oversight for a number of years before decommissioning and after decommissioning completion.

Once baseline conditions and volumes of waste to be dealt with are estimated and the alternative end-points are chosen, methods of accomplishing the decommissioning that will meet the end-point goals can be selected. Preliminary estimates of waste, assuming no components are reusable, are 100 cubic meters of low-level radioactive waste, 2800 cubic meters of concrete waste, 55000 kilograms of non-activated recyclable steel, 9000 kilograms of non-activated recyclable copper, and 11000 kilograms of miscellaneous material. The effectiveness of the methods, their ability to keep personnel exposure ALARA and potential for negative impact on the environment are important criteria applied in choosing the decommissioning methods.

Finally, the waste streams to be managed during decommissioning are to be analyzed in the decommissioning plan, their characteristics and volumes estimated, and treatment and disposal options evaluated. There will be multiple waste streams to be managed during the decommissioning of BAF. Some will be able to be treated and disposed of locally, such as recyclable metals and concrete waste, while some, low level radioactive waste, and hazardous waste, will be shipped off site for disposal.

### 7.2. Baseline Conditions

Establishing the expected baseline conditions of the facility at the end of its operating life can be accomplished by estimating the radioactivity levels and physical conditions based on calculations, design features, operating procedures and waste management requirements. The C-A Department operating procedures, C-A

Environmental Management System, and BNL SBMS subject areas will provide up to date and current information on the BAF operating history, activation history, environmental impact, and waste generation and disposal history to help establish the baseline conditions. Design features that help mitigate the impact of potentially high activation levels on the baseline are being incorporated into the BAF design. Examples of such features are beam loss monitors and cutoff devices to ensure that beam loss criteria are met thereby reducing inadvertent activation of materials. An impermeable liner will be installed on top of the beam tunnel and target room soil shielding to minimize infiltration of surface water to the activated soil area. The beam line cooling system is a closed loop system minimizing the amount of activated water to be disposed of. These features can potentially have a large impact on the cost of the decommissioning since they will help ensure that large volumes of soil or water will not have to be handled as low-level radioactive waste, and control of the beam will minimize activation of magnets and other beam line components. The estimate of 100 cubic meters of low-level radioactive waste for decommissioning includes activated soil removal.

Additionally, methods in place in C-A Department operating procedures and management systems that track spills and spill response actions, that record information from beam-loss events, and that record component replacements will aid in establishing the baseline. Records of hazardous or radioactive wastes and personnel radiation dose will be maintained for tracking purposes and will provide additional baseline information. Records to be consulted will include history of equipment, as-built drawings and records of changes from the baseline conditions.

The decommissioning plan will include requirements for characterizing the facility after operations are shut down and before decommissioning begins. This characterization will confirm or re-establish the baseline conditions, will be used in performing a risk assessment to support the decommissioning safety assessment, and will help establish surveillance and maintenance required to maintain the facility in a safe standby mode until decommissioning begins.

### 7.3. End Point Goals

The overall BAF end-point goals will be stated early during deactivation planning because they will form the basis for specific decommissioning goals and activities that must take place. The goals for the safety basis of the deactivated BAF will be established, and determination will be made of decommissioning protection measures.

Determining the desired product, the final site-configuration and the risks present are essential to planning the decommissioning alternatives for the facility. The decommissioning plan will address the baseline conditions and consider all the alternatives. The decommissioning alternatives that may be evaluated are: (1) reuse for a similar function, (2) safe storage, (3) Brownfield condition, (4) Greenfield condition. Greenfield means that the BAF site will be returned to its original condition with no remediation or institutional controls required. Brownfield means that some remediation or institutional control will be required such as ground water or soil activation that will be monitored. It is assumed that institutional control will remain in effect under Federal oversight for a number of years before decommissioning and a number of years after decommissioning.

The process of determining the alternative that would be most cost-effective and that would provide the least amount of exposure of workers to radiation will involve consideration of the pros and cons of each alternative. For example, the BAF Support Laboratories should be clean and could be considered for future re-use or be dismantled immediately. On the other hand, beam-line components and the beam dump will be activated and require some decay time before decommissioning begins. The safest and most cost-effective alternative for the BAF will probably be a combination of removal of activated items, a period of safe storage, and future re-use of components and buildings.

#### 7.4. Decommissioning Methods

Decommissioning methods will be chosen based on radiological conditions at the BAF at the time of decommissioning and the effectiveness of the methods to achieve the desired end use of the buildings. Additional criteria in choosing the methods are the ability of the methods to keep personnel exposure ALARA and to protect the environment and worker. For example, based on activation calculations, the Support Laboratories and power-supply building can be contact handled at shutdown of operations, while the beam line tunnel and beam stop areas and components may require up to five years to decay to before they can be contact handled. While decontamination is not a large part of the BAF decommissioning, certain areas and equipment such as activated vacuum pipe or activated shielding can have their surfaces become dispersible via moist air and subsequent corrosion. Decommissioning will have standard surface contamination techniques applied. Therefore, a variety of techniques and removal methods will be analyzed to select the approach that accomplishes the goals and optimizes safety to the workers and protection of the environment as well as efficiency.

The decommissioning plan will describe methods that accommodate these varying conditions while maintaining ALARA principles as the basis for the cost estimate. Design features that will reduce personnel exposure as well as decommissioning costs will be addressed. The plan will address the conditions and hazards in detail and will have the benefit of additional information and technologies not yet available. The activation levels should be known in detail, which will allow determination of protection requirements to prevent unwarranted exposure of the workers to radiation.

#### 7.5. Waste Streams

Recyclable materials and wastes anticipated from the decommissioning operation will be identified in the decommissioning plan. Initially, BAF structures and process equipment will be inventoried. Accordingly, the resulting inventory will be comprised largely of process components and structures that are either potentially recyclable, e.g. scrap metal, electrical equipment, or beam line components, or are solid waste. Based on the general nature of the decommissioning operations and the applicable requirements, an all-inclusive list of waste categories will be identified as part of the decommissioning plan. That list will include recyclable metals and equipment and any beam-line components saved for re-use for completeness even though they might not be classified as not solid wastes under the Resource Conservation and Recovery Act. Initial estimates

of waste for Greenfield conditions are 100 cubic meters of low-level radioactive waste, 2800 cubic meters of clean concrete, 55000 kilograms of clean recyclable steel, 9000 kilograms of clean recyclable copper, 11000 kilograms of clean miscellaneous waste, of which some electrical equipment may be recyclable. The 15000 cubic meters of earth-berm soil will be stockpiled and re-graded following tunnel and component removal. Soils containing tritium and Na-22 are included in the 100 cubic meters of low-level radioactive waste. Initial estimates of activation of components, assuming a 4 to 5 year decay period before decommissioning, shows no need for remote handling of waste, and it is anticipated that all waste will be contact handled. The decommissioning plan will review this assumption so that safe and efficient waste handling and disposal methods can be determined.

Waste treatment facilities and processes in place at the time of decommissioning will be reviewed as part of the decommissioning plan. Several low-level radioactive waste disposal facilities, such as Hanford, are currently used by the BNL Waste Management Division today, and it is assumed these facilities, or equivalent facilities, will be available in the future. Cost estimates for waste disposal will be made at the time of decommissioning plan development.

#### 7.6. Regulatory Requirements

The decommissioning plan will delineate the applicable New York State and Federal laws, consensus standards, DOE directives and other requirements applicable to the decommissioning activities, especially those required to meet the end-point criteria.

Regulations affecting decommissioning fall into three categories:

- Those that directly affect decommissioning, e.g., the removal of radioactive materials as needed to reduce risk.
- Those that protect the worker and the public during decommissioning operations.
- Those that apply if hazardous or toxic materials are present in the facility.

A number of DOE orders and Federal regulations actually cover two or more of these categories, so there may be overlapping requirements across categories. Sound planning for interacting with the regulatory agencies and compliance with these regulatory requirements is critical to timely and successful completion of decommissioning activities and will be an integral part of the initial planning activities.

## 8. Chapter Eight, References/Acronyms/Units/Links

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## 8.2. Acronyms

AGS – Alternating Gradient Synchrotron  
ASE – Accelerator Safety Envelope  
AtR – AGS to RHIC Transfer Line  
ATS – Assessment Tracking System  
BAF – Booster Applications Facility  
BNL – Brookhaven National Laboratory  
BSA – Brookhaven Science Associates  
BTMS – Brookhaven Training Management System  
C-A – Collider-Accelerator  
CA – Controlled Access  
CAP88-PC - Clean Air Act Computer Code  
CASIM – Cascade Simulation Computer Code  
CFR – Code of Federal Regulations  
DCG – Derived Concentration Guides  
DOE – Department of Energy  
ECR – Environmental Compliance Representative  
EPA – Environmental Protection Agency  
ES&F – Experimental Support and Facilities Division  
ESH – Environment, Safety and Health  
ESHQ – Environment, Safety, Health and Quality  
ESRC – Experimental Safety Review Committee  
FUA – Facility Use Agreement  
HENP – High Energy and Nuclear Physics  
HVAC – Heating, Venting and Air Conditioning  
HZE – High Energy High Z Particles  
IACUC – Institutional Animal Care and Use Committee  
IBC – Institutional Biosafety Committee  
IRB – Institutional Review Board  
ISM – Integrated Safety Management  
ISO – International Standards Organization  
LET – Linear Energy Transfer  
LO/TO – Lock Out / Tag Out  
MCNPX – Monte Carlo Neutron Photon Transport Computer Codes  
MCR – Main Control Room  
MMPS – Main Magnet Power Supply  
NASA – National Aeronautics and Space Administration  
NCRP – National Council on Radiation Protection and Measurements  
NEG – Non-Evaporative Getters  
NESHAP - National Air Emission Standards for Hazardous Air Pollutants  
NFPA – National Fire Protection Association  
NYS – New York State  
OPM – Operations Procedure Manual  
OSHA – Occupational Safety and Health Administration  
P2 – Pollution Prevention

PLC – Programmable Logic Controller  
QA – Quality Assurance  
QA1 – Quality Assurance Category 1  
R2A2 – Roles, Responsibilities, Accountabilities and Authorities  
RadCon – Radiological Control  
RBE – Relative Biological Effectiveness  
RCT – Radiological Control Technician  
RHIC – Relativistic Heavy Ion Collider  
RSC – Radiation Safety Committee  
SACR – Scientific Advisory Committee for Radiobiology  
SAD – Safety Assessment Document  
SAR – Safety Analysis Report  
SBMS – Standards Based Management System  
SCDHS – Suffolk County Department of Health Services  
SPDES – State Pollution Discharge Elimination System  
SWIC – Segmented Wire Ionization Chamber  
STP – Sewage Treatment Plant  
TLD – Thermo-Luminescent Dosimeter  
TTB – Tandem to Booster Transfer Line  
TVDG – Tandem Van De Graaff  
UL- Underwriters Laboratories

### 8.3. Units

GeV – billion electron volts  
MGD – million gallons per day  
mT – milli-Tesla, a unit of magnetic field strength  
mrad – millirad, a unit of absorbed dose  
mrem – millirem, a unit of dose equivalent  
ppm – parts per million  
torr – unit of pressure  
 $\mu\text{Ci}$  – micro-curie, unit of radioactivity

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8.4.39. Standards Based Management System, <https://sbms.bnl.gov/ch00d011.htm>

8.4.40. Technical Basis for Bioassay,  
<http://www.rhichome.bnl.gov/AGS/Accel/SND/Bioassay/BioassayTechBasis.doc>

8.4.41. Training and Qualification Management System,  
<https://sbms.bnl.gov/mgtsys/ms0u/ms0ud011.htm>

## Estimates of Radiological Quantities Associated with the Booster Applications Facility

A.J. Stevens

### I. Source Terms Assumed

In making estimates of quantities associated with radiation fields, it is necessary to make assumptions regarding the energy and intensity of the source of radiation. In this document, the “typical” sustained intensity/energy in an hour is assumed to be the equivalent of  $10^{10}$  ~3 GeV nucleons per 3 seconds or  $1.2 \times 10^{13}$  3.07 GeV nucleons per hour<sup>1</sup> on target. However, occasional runs corresponding to  $6 \times 10^{14}$  GeV on target per hour ( $1.95 \times 10^{14}$  3.07 GeV nucleons per hour) may occur.

The annual beam is taken to be the equivalent of  $10^{17}$  GeV.<sup>2</sup> This source term, which assumes 1500 hours per year, was derived from previous NASA running at the AGS. It corresponds to the total accelerated beam in the Booster – less being delivered to the BAF target room. In fact, many runs are anticipated with very low intensity transported to the BAF tunnel, which is achieved by a small stripping wire in front of the thick extraction septum. In estimating annual radiological quantities below, it is generally assumed that 90% of this annual beam is lost on or near the (thick) Booster extraction septum. In order to permit flexibility of BAF operations, a conservative allowance for 30% of this annual beam on target is made. Thus, a total of  $3 \times 10^{16}$  GeV per 1500 hour year may be delivered to the BAF target room. The *average* hourly rate of  $2 \times 10^{13}$  GeV is, of course, *much* lower than the maximum hourly rate of  $6 \times 10^{14}$  GeV and lower than the typical “sustained” hourly rate of  $3.68 \times 10^{13}$  GeV posited in the preceding paragraph.

The purpose of this document is to estimate radiological quantities associated with operation of the BAF. Often, since much of the beam loss associated with this operation takes place within the Booster tunnel, quantities in the immediate vicinity of the Booster are estimated. However, it should be noted that regulatory aspects of beam loss within the Booster tunnel fall under the “umbrella” of Booster operation. As an example, the Environmental Assessment statement for the BAF relates only to quantities external to the Booster, i.e., to the BAF target room, and the transport line connecting the target room to the Booster.

### II. Prompt Radiation Levels

#### A. Exterior to the Target Enclosure

The target room is surrounded by 4 ft. of concrete and 11 ft. of earth. Use of the Tesch formula<sup>3</sup> for this shield thickness obtains  $2.42 \times 10^{-17}$  rem per 3.07 GeV proton. For the typical sustained loss of  $1.2 \times 10^{13}$  protons per hour, 0.29 mrem per hour on top of the berm results. The maximum hourly rate is 4.73 mrem per hour and the average is 0.16 mrem per hour.<sup>4</sup>

Fig. 1 shows a sketch of the elevation view of the BAF target room and beam dump areas. The light shaded areas are light concrete and the darker area steel. To estimate the dose on top of the berm shown, a CASIM<sup>5</sup> calculation was done in a cylindrically symmetric approximation of the materials shown. The results are shown in Fig. 2 for a plastic target, again at 3.07 GeV. (Plastic is believed to be a reasonable approximation of the specimens that will be the actual targets.) In Fig. 2, the origin of the Z (beam) coordinate is at the beginning of the target room. The beginning of the downslope (Fig. 1) is indicated in this figure, as is the value of the simple Tesch formula, which is surprisingly close to the CASIM estimate. The CASIM star density was less on the downslope than one the top so that the estimate of  $\sim 0.3$  mrem/hr for the typical sustained beam on target for the target room/dump area appears to be reasonable. Activation in the soil near the dump is considered in the next section.

#### B. Exterior to the BAF Beam Line and Booster

Upstream of the target room, as well as above the Booster tunnel, the shielding is comprised of 15 ft. of earth. For the purposes of estimating hourly dose rates, a 5% loss of the maximum beam on target is assumed. The Tesch formula gives  $4.52 \times 10^{-17}$  rem per 3.07 GeV proton at the edge of the berm. A 5% loss of the *maximum* hourly loss would give 0.44 mrem per hour. The “typical” and average hourly rates for a 5% loss correspond to 0.027 mrem per hour and 0.015 mrem per hour respectively.

In the Booster tunnel, the maximum dose on the top of the berm is assumed to correspond to 25% beam loss on the thick septum.<sup>6</sup> For the typical maximum hourly rate (losing  $4.0 \times 10^{12}$  on the septum), the Tesch formula<sup>7</sup> gives 0.06 mrem per hour.

#### C. At the Support Building

The support building is separated from the Target Room by a labyrinth, which is shown in Fig. 3. The labyrinth was simulated by using the MCNPX code.<sup>8</sup> The circled numbers on this sketch represent points at which the dose due to neutrons  $< 20$  MeV was calculated, which is very nearly all the dose at the closest people should be when the beam is on (circled 4 in Fig. 3). The results for both an Fe target and a plastic target (each 12 cm long) are shown in Table 1.

Table 1. MCNPX Dose from 3.07 GeV Protons (See Fig. 3)

Point (Target)	Dose(rem/p) from $n < 20$ MeV
1 (Fe)	$5.29 \pm 0.08 \times 10^{-13}$
2 (Fe)	$1.70 \pm 0.04 \times 10^{-14}$
3 (Fe)	$3.47 \pm 0.18 \times 10^{-16}$
4 (Fe)	$5.00 \pm 0.71 \times 10^{-18}$
3 (Plastic)	$9.43 \pm 0.18 \times 10^{-17}$
4 (Plastic)	$7.79 \pm 0.18 \times 10^{-19}$

Since, as mentioned above, plastic is more representative of most BAF targets, a reasonable allowance at the gate position (Point 4) is  $10^{-18}$  rem/p. For the typical sustained beam of  $1.2 \times 10^{13}$  protons per hour, 0.012 mrem results. The maximum beam rate gives about 0.2

mrem per hour. The annual allowance of beam on target of  $3 \times 10^{16}$  GeV ( $9.77 \times 10^{15}$  3.07 GeV nucleons) would result in an estimated dose of 10 mrem for the full 1500 hours.

### III. Groundwater Activation

#### A. Method of Estimation

Groundwater activation is estimated within the context of a model developed by Ed Lessard that is described in the AGS SAD. The essential features of this model (which time averages over a year) will be briefly recapitulated here for completeness.

The general concern is that radionuclides produced in the soil by spallation migrate to the water table by leaching, and eventually to potable water sources. It is well known that the two radionuclides which are of the most concern in soil are  $^{22}\text{Na}$  and  $^3\text{H}$  (tritium), all others being either too difficult to produce or too short lived to be of concern. Measurements have been made of the probability of producing both of these nuclides per “CASIM star”, i.e., per inelastic reaction estimated by the CASIM program.<sup>10</sup> The model of Lessard posits that rainwater recharges a “hot spot” of radionuclide production 12.8 times per year, leaching the nuclides to the water table without dilution. Quantitatively, application of the model results in the following activity concentrations (in water at the water table) for  $1.5 \times 10^{11}$  CASIM stars/cc-year:

$$\begin{aligned} &4.17 \times 10^5 \text{ pCi/l for } ^3\text{H and} \\ &5.00 \times 10^4 \text{ pCi/l for } ^{22}\text{Na} \end{aligned}$$

This model is very conservative, as it ignores both dilution at the water table, and further dilution during (very slow) transport to the nearest potable source. Nonetheless, recent BNL policy has been to mitigate possible groundwater activity by installing geomembrane liners over the soil whenever the concentrations obtained in this model approach the regulatory limits for drinking water of 20000 pCi/l for  $^3\text{H}$  and 400 pCi/l for  $^{22}\text{Na}$ . These liners simply act as umbrellas to inhibit the transport of the radionuclides to the water table.<sup>11</sup> The remainder of this section reports the results of CASIM calculations and application of this model.

#### B Radionuclide Production Exterior to the Target Enclosure

Fig. 4 shows (again) an elevation view of the dump region. The circled points 1 and 2 indicate the nearest points (to the target) in soil below and above the dump materials. Fig. 5 shows the plan view; here the circled points 3 and 4 (on the horizontal mid-plane) again indicate relatively close points in soil. A fully 3-dimensional CASIM calculation was performed (again with a plastic target at 3.07 GeV) examining various regions around the dump including those indicated. The highest star density found was immediately beneath the floor of the dump – point 1 in Fig. 4, where the value is  $1.7 \times 10^{-8}$  stars/cc-p. Scaling to the annual equivalent of  $9.77 \times 10^{15}$  nucleons gives  $1.66 \times 10^8$  stars/cc-yr. In the model adopted, this translates to 461 pCi/l of  $^3\text{H}$  and 55 pCi/l of  $^{22}\text{Na}$ . Note that the presence of the floor itself prevents leaching in any case

at this point. The worst case that is leachable turns out to be point 3 in Fig. 5. This is lower by a factor of 1.6, giving 288 pCi/l of  $^3\text{H}$  and 34 pCi/l of  $^{22}\text{Na}$ .

### *C Radionuclide Production at Booster Extraction*

The situation at the Booster extraction septum is much more complicated. Recall that allowance is made for 90% of the annual beam of  $10^{17}$  GeV interacting in the region of the septum. Now most of this loss corresponds to low intensity running in the BAF line where a small fraction is stripped to the correct charge state for transport into the BAF tunnel. Presumably the off-charge ions interact in Booster elements downstream of the septum. Since the nearest quadrupole is only 8 ft. away from the middle of the septum, all the loss will be treated as if it occurred on the septum itself.

Interactions in (or near) the septum give rise to soil star density in two quite separate regions of soil. The Booster tunnel close to the septum is quite straightforward. Here a simple CASIM estimate (of the maximum star density in a tunnel at a transverse distance of 3.5 ft.) gives the result of  $2.8 \times 10^{-7}$  stars/cc-p at 3.07 GeV. The annual loss is the equivalent of  $2.93 \times 10^{16}$  3.07 GeV nucleons, giving  $8.2 \times 10^9$  stars/cc-yr. Making the “usual” scaling to 90% of  $2 \times 10^{16}$  at 2 GeV, and applying the model of Lessard gives 22,800 pCi/l of  $^3\text{H}$  and 2733 pCi/l of  $^{22}\text{Na}$ , both exceeding the drinking water limit, and the latter by a considerable margin.

However, the region above this point is already covered by a liner. This is shown in Fig. 6, which also illustrates the other region of concern, namely the soil on the opposite side of the Booster tunnel, at a nominal  $0^\circ$  production. The geometry sketched in Fig. 6 was simulated in CASIM, complete with magnetic fields in both the septum and the first two dipoles downstream. The star density was binned on the mid-plane on the opposite side of the Booster wall. The curved lines in Fig. 6 are supposed to represent the “smoosh” of secondaries which enter the soil. The maximum star density in this region was found to be  $2.3 \times 10^{-7}$  stars/cc-p at 3.07 GeV, 82% of the estimate immediately above. However, as indicated by the dotted line in Fig. 6, which indicates the approximate position of the existing liner, this region is not currently covered by a liner. Fig. 7 is the same as Fig. 6, but with an extension of the liner shown. Extrapolation of the star density obtained in the CASIM runs to this position indicates a reduction factor of leachable nuclides by a factor of  $\sim 14$ . The leachable  $^{22}\text{Na}$  would be reduced to  $\sim 160$  pCi/l in Lessard’s model. It should be kept in mind that this estimate is conservative for two reasons: (1) the CASIM star density is likely overestimated<sup>10</sup> and (2) the average energy corresponding to most of the loss is expected to be much lower than 3 GeV per nucleon.

## **IV. Skyshine**

The annual dose from skyshine is estimated from the parameterization of measurements made at the AGS by Distenfeld and Colvett.<sup>12</sup> Their results can be expressed as:

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$$Dose\ in\ rem / neutron > 20\ MeV = \frac{4.17 \times 10^{-13} \times e^{-D/600} \times (1 - e^{-D/47})}{D^2}$$

where D is the lateral distance from the source to the point of consideration in m. To make use of this formulation, an estimate must be made of the total number of neutrons per year (> 20 MeV) emerging from the berm.

From the source term discussion in Section I, it is clear that only the two regions – above the Booster extraction septum and above the target room – need to be considered. In both cases,<sup>13</sup> the CASIM program is used to estimate the star density at the surface. The number of neutrons per interacting proton can be estimated by the following:

$$n > 20\ MeV / proton = \left(\frac{\pi}{2} \times R\right) \times 2.06 \times \lambda \times \int_Z SD(Z) dZ$$

The explanation of this expression is as follows.  $SD$  is the CASIM star density at the outer berm radius  $R$  and some point in the beam direction  $Z$ .  $\lambda$  is the high energy (>47 MeV) neutron interaction length which is 53.3 cm in BNL soil. The quantity  $\lambda \times SD$  is the flux (neutrons per  $cm^2$ ) at  $R, Z$  above the CASIM threshold of 47 MeV and the 2.06 factor corrects this to the flux above 20 MeV.<sup>14</sup> An area on the berm surface of  $dA = (\pi/2) \times R \times dZ$  corresponds to considering a vertical half angle of  $\pm 45^\circ$  to be the radiating surface. The integral over the beam direction then gets the total neutrons. The approximation is overlaid on the actual Booster cross section at the septum position in Fig 8. It should be clear that this geometric approximation is conservative. Having performed the integral in the fashion indicated, the skyshine dose is considered to emanate from two single points, one above the Booster septum, and one above the end of the target room.

In this case, for historical reasons, the CASIM calculations were done at a 2 GeV beam energy. The results of these calculations, the integration, and the annual source (90% and 30% of  $5 \times 10^{16}$  2 GeV nucleons per year) give the following:

$$rem / year (Booster\ Septum) = \frac{3.28 \times e^{-D/600} \times (1 - e^{-D/47})}{D^2}$$

$$rem / year (Target\ Room) = \frac{1.0 \times e^{-D/600} \times (1 - e^{-D/47})}{D^2}$$

The target room is much smaller as a source because the source is smaller in magnitude and the beam dump provides better shielding.

The entrance of the BAF support building is 25m from the Target Room source, which results in 0.63 mrem/yr and 85m from the Booster septum which gives 0.33 mrem/yr. The total of these is about a factor of 10 lower than the estimated direct radiation (Section IIC above).

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The closest building which is (at least at times) uncontrolled is Bldg. 919, which is about 137m from the Booster septum (0.13 mrem/yr.) and 70m from the Target Room source (0.14 mrem/yr.) Other nearby locations with more than transient occupancy include Building 914 (a radiation area) which is 57m from the Booster septum (0.63 mrem/yr.) and the BLIP facility (Bldg 931A), 67m from this point (0.50 mrem/yr.). Both locations are ~ 900m from the site boundary, which gives ~ .001 mrem/yr. from the Booster and ~ .0003 mrem/yr. from the Target room. None of these numbers gives cause for concern.

### V. Air Activation in the Target Room

Unlike some other accelerator facilities, ventilation of the Target Room in the BAF is planned. This section estimates the radionuclides produced in air that will be vented. The composition of air is taken to be <sup>15</sup> 78.08% N<sub>2</sub>, 20.95% O<sub>2</sub>, 0.03% CO<sub>2</sub>, and 0.93% A, trace elements being ignored. The spallation cross sections for radionuclide production are shown in Table 1.

**Table 1. Cross Sections for Radionuclide Production from Ref. [16]**

Parent	Isotope	Half-Life	Cross Section (mb)
N	<sup>13</sup> N	10m	10
	<sup>11</sup> C	20.4m	10
	<sup>7</sup> Be	53.6d	10
	<sup>3</sup> H	12.2y	30
O	<sup>15</sup> O	2.1m	40
	<sup>14</sup> O	74s	1
	<sup>13</sup> N		9
	<sup>11</sup> C		5
	<sup>7</sup> Be		5
	<sup>3</sup> H		30
A	<sup>35</sup> S	87d	23
	<sup>32</sup> P	14.3d	25
	<sup>28</sup> Al	2.3h	13
	<sup>22</sup> Na	2.6y	10
C	<sup>11</sup> C		30
	<sup>7</sup> Be		10
	<sup>3</sup> H		10

In addition to these nuclides from spallation, <sup>41</sup>A (t<sub>1/2</sub> = 1.8h) is produced from <sup>40</sup>A by thermal neutrons with a huge (630 mb.) cross section.

The general strategy here was to estimate the concentration of any particular isotope from the expression

$$N_I = \phi(\theta, R) \times \sigma \times N_p$$

Here  $N_p$  is the number of parent nuclei per unit volume,  $N_I$  the same for the isotope in question,  $\sigma$  the cross section in Table 1, and  $\phi$  the irradiating flux, which is a function of position in the room. In fact, there are 3 separate irradiating fluxes. The first is the proton beam in air in the Target Room, the second corresponds to hadrons  $> 20$  MeV emerging from the target posited to exist, and the third (for  $^{41}\text{A}$  only) the thermal neutron flux. The cross sections in Table 1 are assumed to be independent of energy above 20 MeV.

For evaluation of the fluxes another MCNPX calculation was done. The target was again taken as plastic and placed inside a 20 ft. by 20 ft. by 10 ft. enclosure (basically the Target Room in Fig. 3 without a labyrinth or recessed dump area) surrounded by 1 ft. thick concrete walls. The beam was taken as 2 GeV and all the results were scaled to the annual beam of  $1.5 \times 10^{16}$  particles (see Section I.) In this simulation, flux of neutrons, protons, and pions above 20 MeV (as well as neutrons  $< 10^{-7}$  MeV) were calculated in various angular intervals at two distances. The flux for particles  $> 20$  MeV was observed to fall like  $1/R^2$  to a high degree of accuracy in any angular interval. Fig. 9 shows the coefficient for the neutron flux as a function of angle. For example, the neutron flux at  $16^\circ$  emerging from the target was found to approximately be

$$\text{neutrons/cm}^2 = \frac{0.2}{R^2}$$

It was found that multiplying the neutron flux by 2.25 was a somewhat over-generous way to account for the protons and pions present. The room averaged flux of secondaries  $> 20$  MeV was then estimated by averaging the expression above multiplied by 2.25 over a sphere with the same volume as the room.<sup>17</sup> The result was an average flux of  $3 \times 10^{-6}$  hadrons/cm<sup>2</sup>-p  $> 20$  MeV.

After the target, the non-interacting beam is planned to be in air. For the particular target chosen in this simulation (30 cm. long), this is 60% of the beam. If the length of air is 10 ft., a room-averaged flux of  $1.6 \times 10^{-6}$  beam/cm<sup>2</sup> was obtained, and a total of  $5 \times 10^{-6}$ /cm<sup>2</sup>-p was used for the isotope concentration estimate. Clearly the estimate is not very sensitive to how much beam interacts in the target.

The character of the thermal neutron flux was quite different, being essentially constant over the room interior, at about the same value,  $5 \times 10^{-6}$ /cm<sup>2</sup>-p.

Using these room-averaged fluxes, the room-averaged activity concentrations for zero decay time are readily obtained from the information in Table 1.<sup>18</sup> The results are shown in Table 2 below.

**Table 2. Activity Concentrations and Total Activity/yr. Averaged over the Target Room**

Isotope	Ci/cc-y at t = 0.	Ci/yr
<sup>41</sup> A	$3.3 \times 10^{-11}$	$3.8 \times 10^{-3}$
<sup>35</sup> S	$1.0 \times 10^{-15}$	$1.1 \times 10^{-7}$
<sup>32</sup> P	$6.5 \times 10^{-15}$	$7.3 \times 10^{-7}$
<sup>28</sup> Al	$5.0 \times 10^{-13}$	$5.8 \times 10^{-5}$
<sup>22</sup> Na	$4.0 \times 10^{-17}$	$4.5 \times 10^{-9}$
<sup>15</sup> O	$4.8 \times 10^{-9}$	$5.3 \times 10^{-1}$
<sup>14</sup> O	$2.0 \times 10^{-10}$	$2.3 \times 10^{-2}$
<sup>13</sup> N	$1.2 \times 10^{-9}$	$1.3 \times 10^{-1}$
<sup>11</sup> C	$5.0 \times 10^{-10}$	$5.8 \times 10^{-2}$
<sup>7</sup> Be	$1.4 \times 10^{-13}$	$1.5 \times 10^{-5}$
<sup>3</sup> H	$5.5 \times 10^{-15}$	$6.3 \times 10^{-7}$

These numbers are over two orders of magnitude smaller than the corresponding estimates for the RHIC tunnel.

## VI. Hazards from Booster Beam Faults in the BAF Enclosure

A penetration through the Booster shield, about 1 ft. in diameter, was made as the first step in facility construction. This penetration “looks at” the extraction septum at an angle of about 6°, and an obvious early concern was the dose that might come through this penetration due to a Booster beam loss fault near the septum while BAF construction was taking place.

The calculation of this potential hazard was reported earlier,<sup>19</sup> and is not discussed in detail here, only the results are presented here.

Fig. 10 shows the dose per proton in a concrete backstop following the penetration as a function of depth in the concrete. This calculation is for a 2 GeV proton interacting in the Booster extraction septum. At this energy and forward angle, the physics simulation in CASIM is not very good. As shown in Fig. 10, there is a sizable disagreement between the “entrance” dose estimated by CASIM and MCNPX. On the other hand, at the depth represented by the point at bin No. 25 in Fig. 10 (~ 152 cm.), MCNPX has great difficulty with statistical precision. The dashed line in the Figure, about a factor of 3 below the CASIM estimate, was recommended as the best estimate for planning purposes. This line is given by:

$$rem/p = 8.29 \times 10^{-13} \exp(-d/43.4)$$

where  $d$  is the depth in cm. A 12 ft. thick backstop is now in place in this area, and the region is monitored by two interlocking chipmunks.

## References/Footnotes

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1. The kinetic energy is taken from Table 2.3.2 of the BAF CDR.
2. R. Prigl, private communication. This estimate is believed to have a “safety factor” of about 3, most of which is in the average energy.
3. K. Tesch and H. Dinter, Radiation Protection Dosimetry, Vol. 15 No. 2 pp. 89-107 (1986). The expression for a point loss is:  $\text{rem/primary} = (1.5 \times 10^{-12} E^{0.8} \exp(-d/107))/R^2$  where E is kinetic energy in GeV, d the shield thickness (soil or concrete) in g/cm<sup>2</sup>, and R is the transverse distance in m. Here we assume concrete has density 2.35 g/cc and soil 1.8 g/cc. Use of this expression implies a “thick target.”
4. This is a simple-minded scaling by the energy. A more realistic scaling would require knowledge of the programmatic plan for energy per nucleon.
5. A. Van Ginneken, "CASIM; Program to Simulate Hadron Cascades in Bulk Matter," Fermilab FN-272 (1975). CASIM was not “designed” to be accurate at energies this low, and there is some evidence that the program would over-estimate the dose in geometries such as this.
6. More beam can be “lost” if low intensity heavy ion runs in the BAF are being accomplished by a thin stripping foil as described in Section I. However, these runs will be at a much lower energy per nucleon. See discussion in Section III(C).
7. The top of the berm is assumed to be 21 ft. away from the beam line in the Booster. See Fig. 8.
8. H.G. Hughes, R.E. Prael, R.C. Little, “MCNPX – The LAHET/MCNP Code Merger,” X-Division Research Note, 4/22/97. The version number of the code used here is 2.1.5. MCNPX has various physics options; only the default options were used.
9.  $E^{0.8}$  scaling has been applied.
10. These “measurements” were made in relatively transverse geometries at higher energy than considered here. Comparison of CASIM with other hadron cascade codes indicates that CASIM overestimates high energy interactions in the forward direction, which means that some of the star densities (and hence radionuclide production) in this note are very likely overestimated.
11. One negative aspect of liners is that the soil beneath a liner “dries out,” which makes the soil less effective as a prompt radiation shield.
12. C. Distenfeld and R. Colvett, "Skyshine Considerations for Accelerator Shielding Design," Nucl. Sci. Eng. Vol. 26, p. 117 (1966).
13. In these CASIM calculations, the Booster was treated as an open tunnel containing only the beam pipe, the septum magnet, and the first downstream quadrupole. Protons were forced to interact on the septum.

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14. The assumption is made that the neutron spectrum falls off as  $E^{-1.4}$  for  $E > 10$  MeV. The CASIM runs were made at 3 GeV and scaled to 2 GeV by  $E^{0.8}$ .
15. A.J. Stevens, "Air Activation in the Booster Tunnel," AD Booster Technical Note No. 86, (1987).
16. A. Rindi and G.R. Stevenson, "Air Activation in the Target Stations of the SPS," CERN LAB II, RA/Note/73-3 (1973).
17. The integral was performed from  $R = 30$  cm to  $R = 300$  cm. The volume of the room is  $1.13 \times 10^8$  cm<sup>3</sup>.
18. The parent concentrations follow from the composition of air together with the assumption that the air has density 0.0012 g/cc. The  $N_p$  values for A, N, O, and C are respectively  $2.3 \times 10^{17}$ ,  $3.9 \times 10^{19}$ ,  $1.05 \times 10^{19}$ , and  $7.5 \times 10^{15}$  atoms/cc.
19. RSC Minutes of 6/22/1999 meeting.

Figures Follow

Note: Some Indicators of Scale on the Following Figures are Not Correct on the WEB Version of this Document

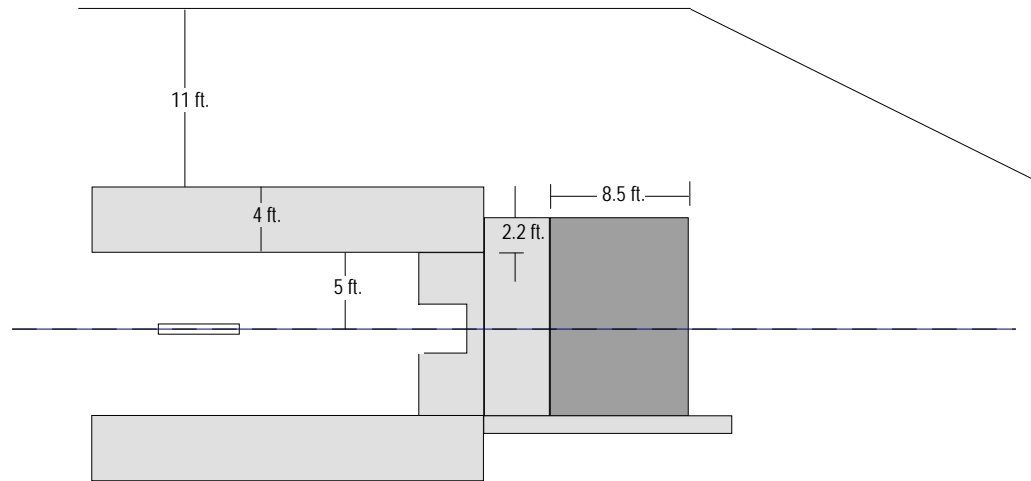


Fig. 1 Elevation View of Enclosure & Dump Region

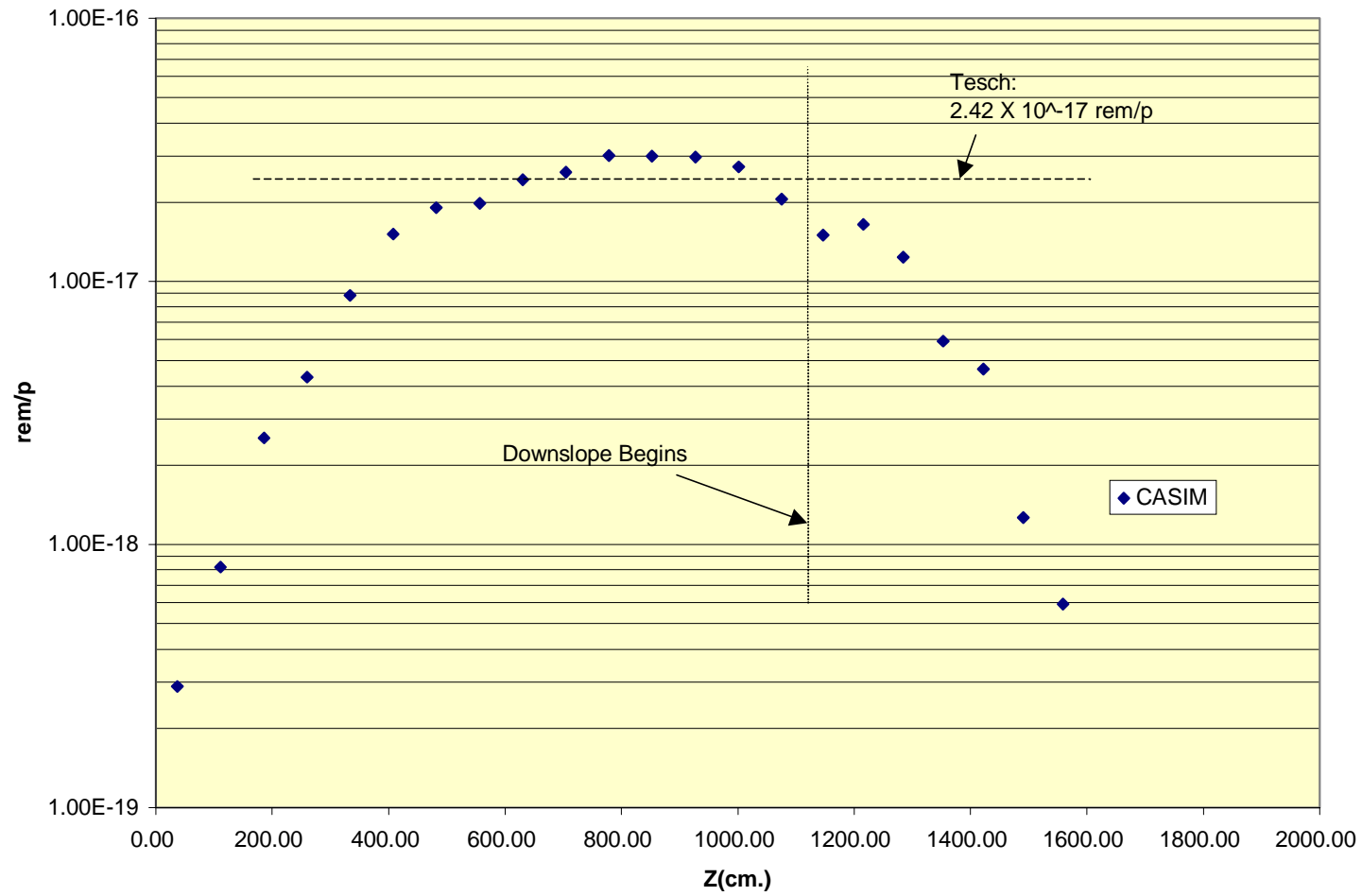
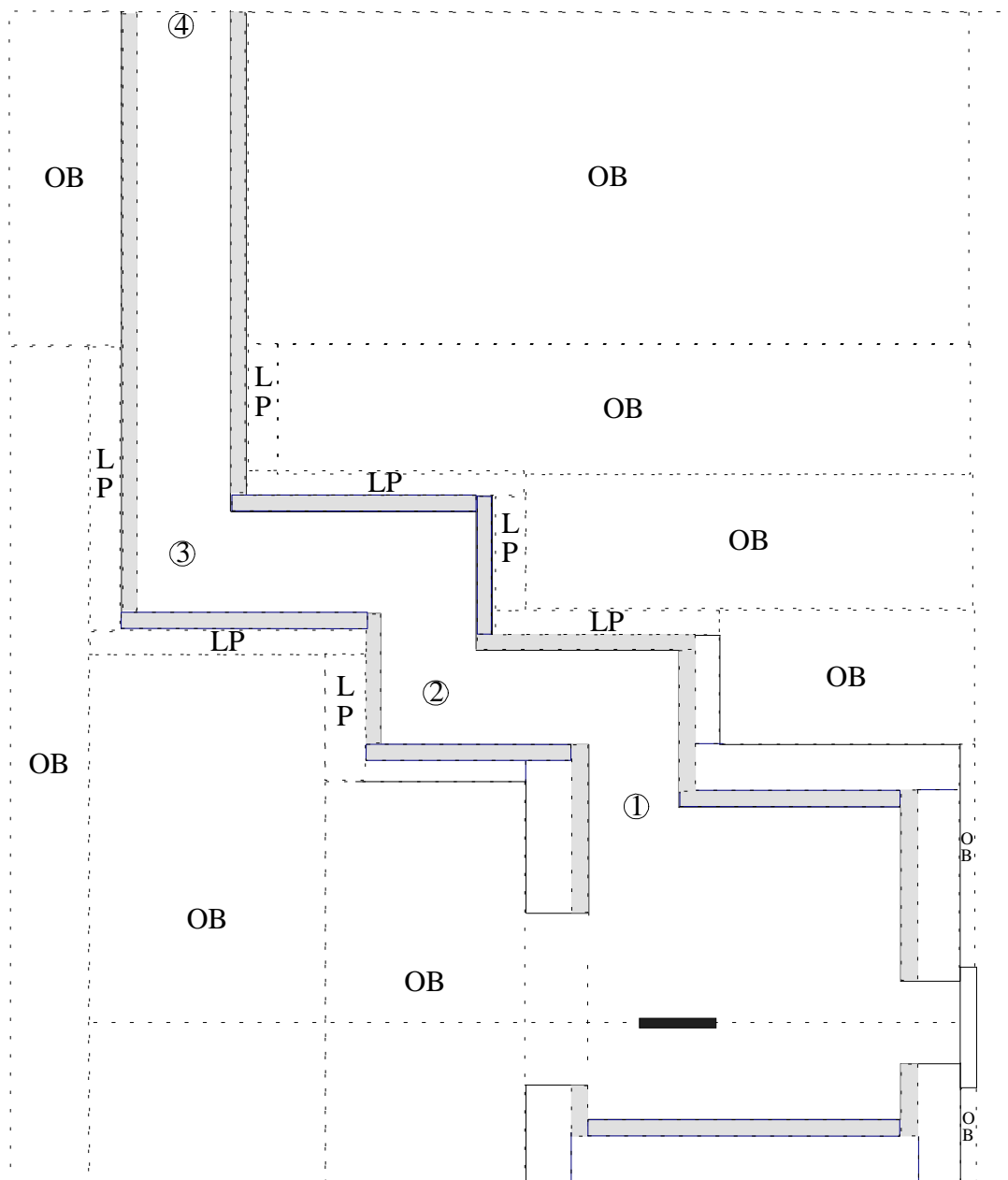


Fig. 2 Dose on the Berm Top

1 inch (drawing) = 10 ft.



(The Labels LP and OB Refer to "Low Probability" and "Out-of-Bounds" Regions in the MCNPX Calculation)

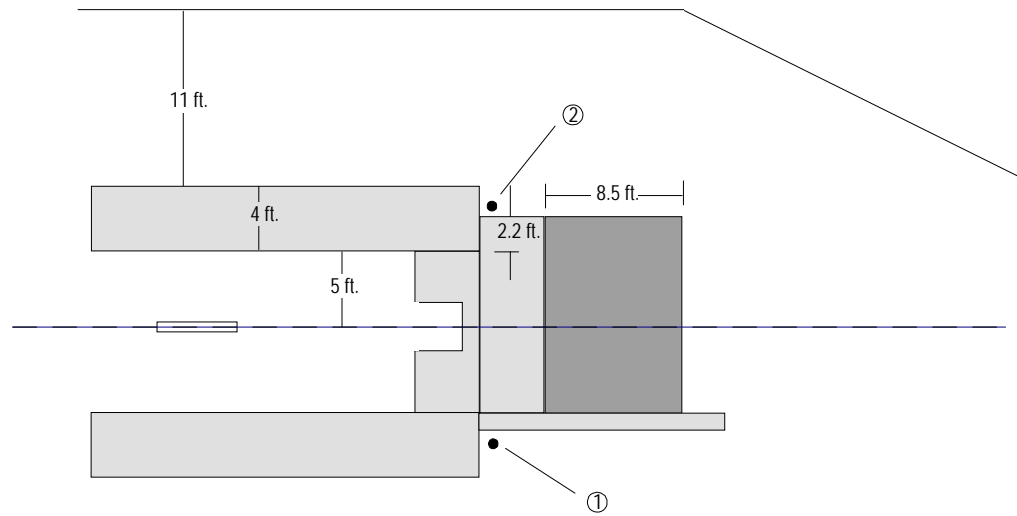


Fig. 4 Elevation View of Enclosure & Dump Region

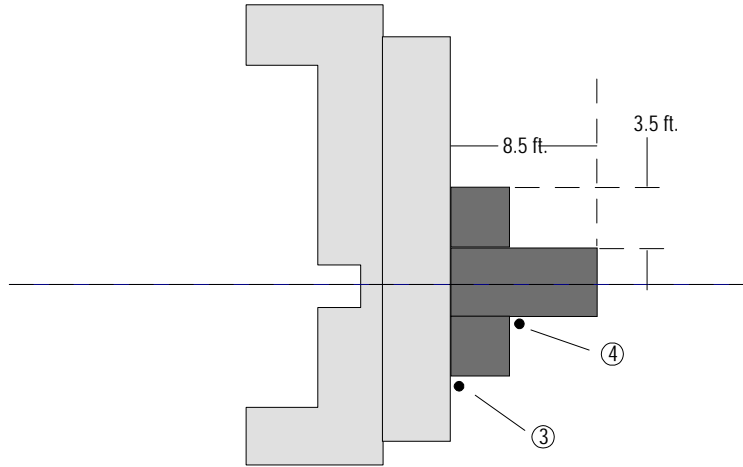


Fig. 5 Plan View of Dump Region

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2 inches = 42 ft.

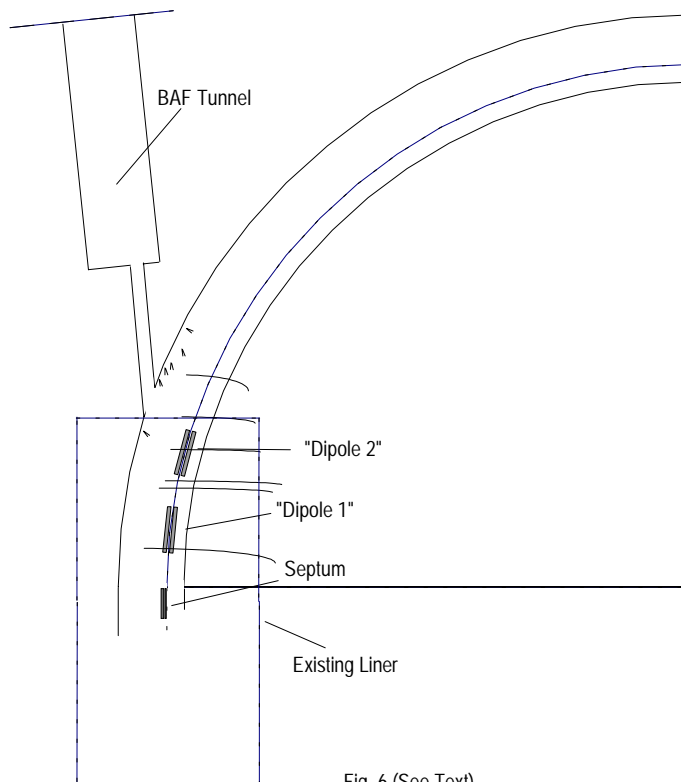


Fig. 6 (See Text)

## BAF SAD Appendix 1

2 inches = 42 ft.

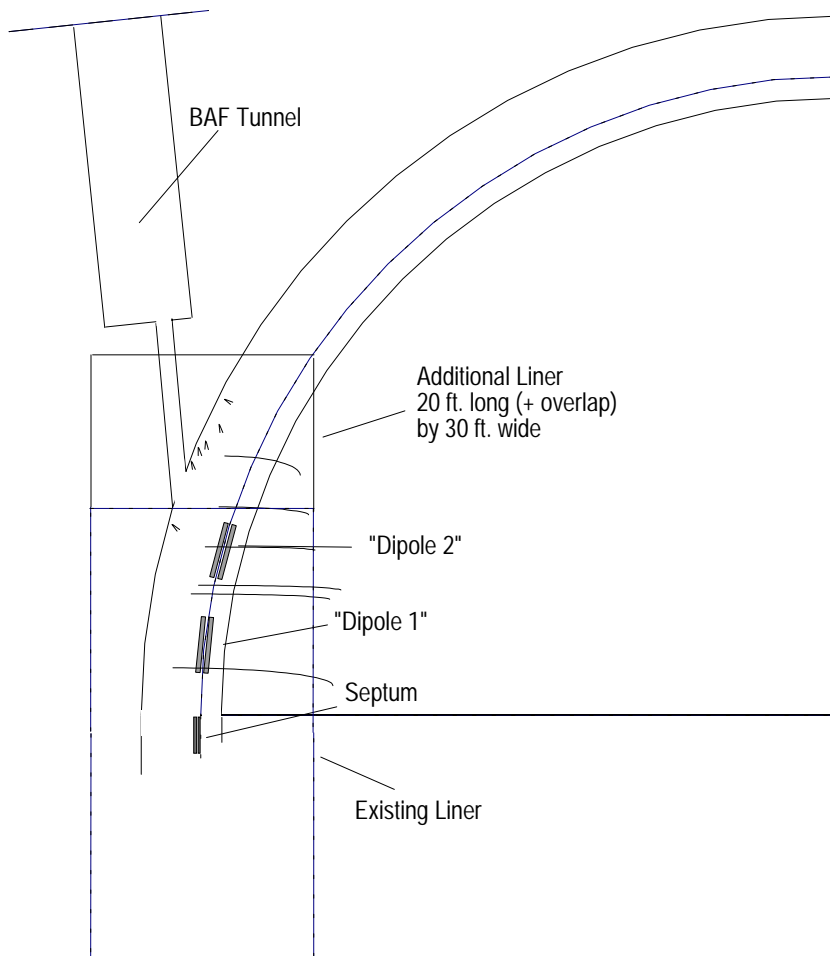


Fig. 7 Same as Fig. 6, but showing Additional Liner

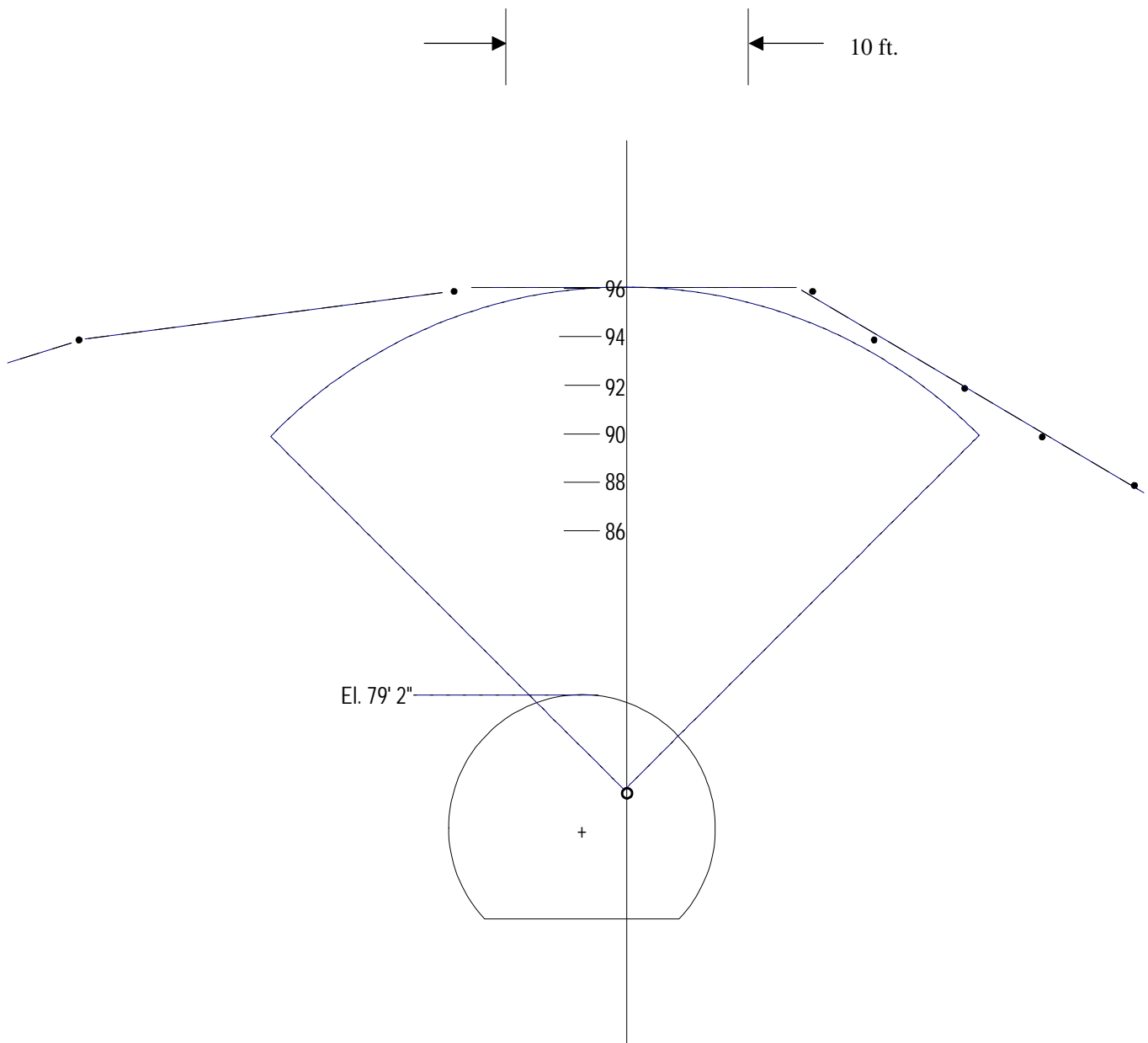


Fig. 8 Cross Section for Skyshine Estimate

### Coefficient for N Flux

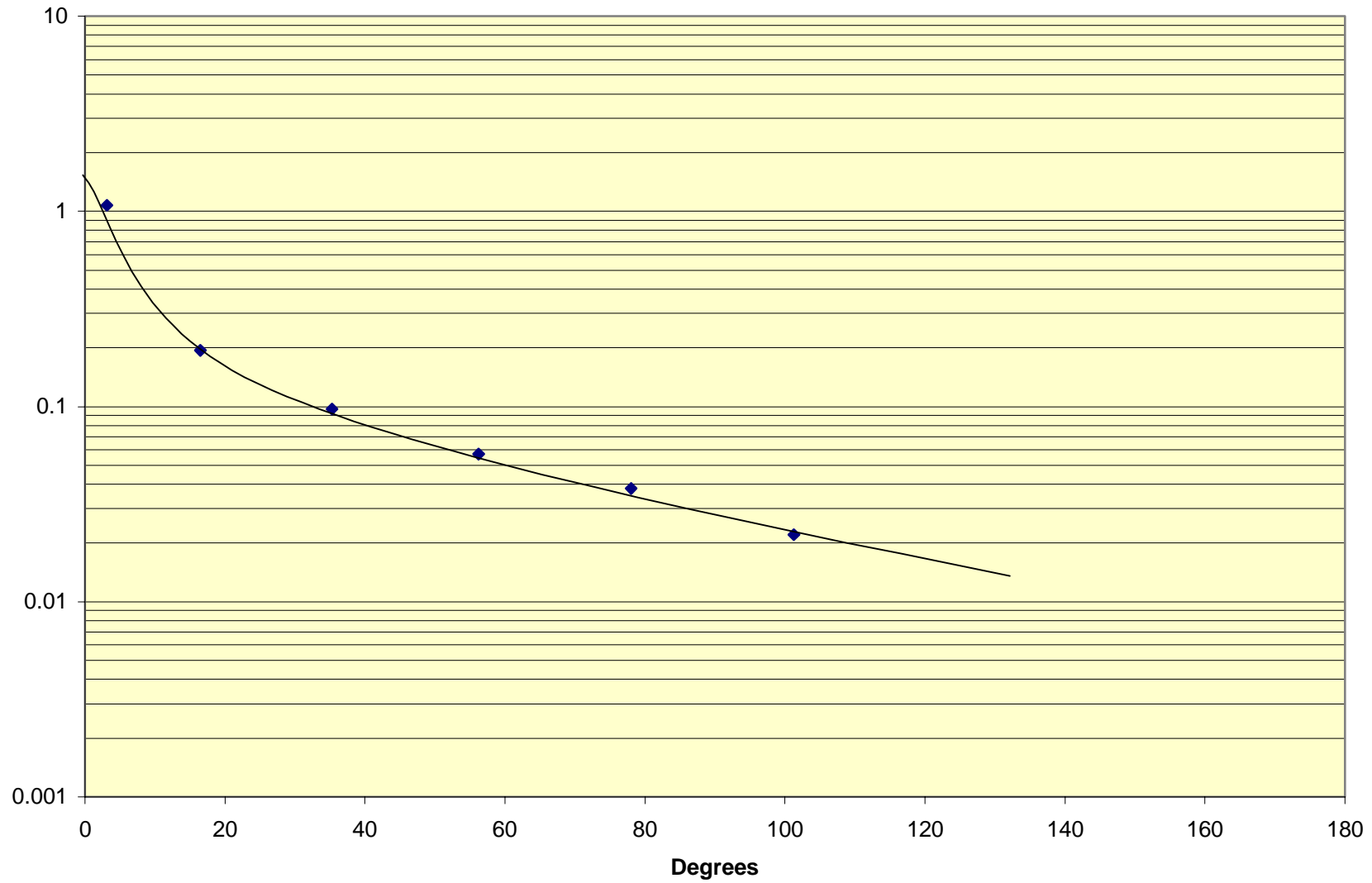


Fig. 9 (See Text)

## BAF SAD Appendix 1

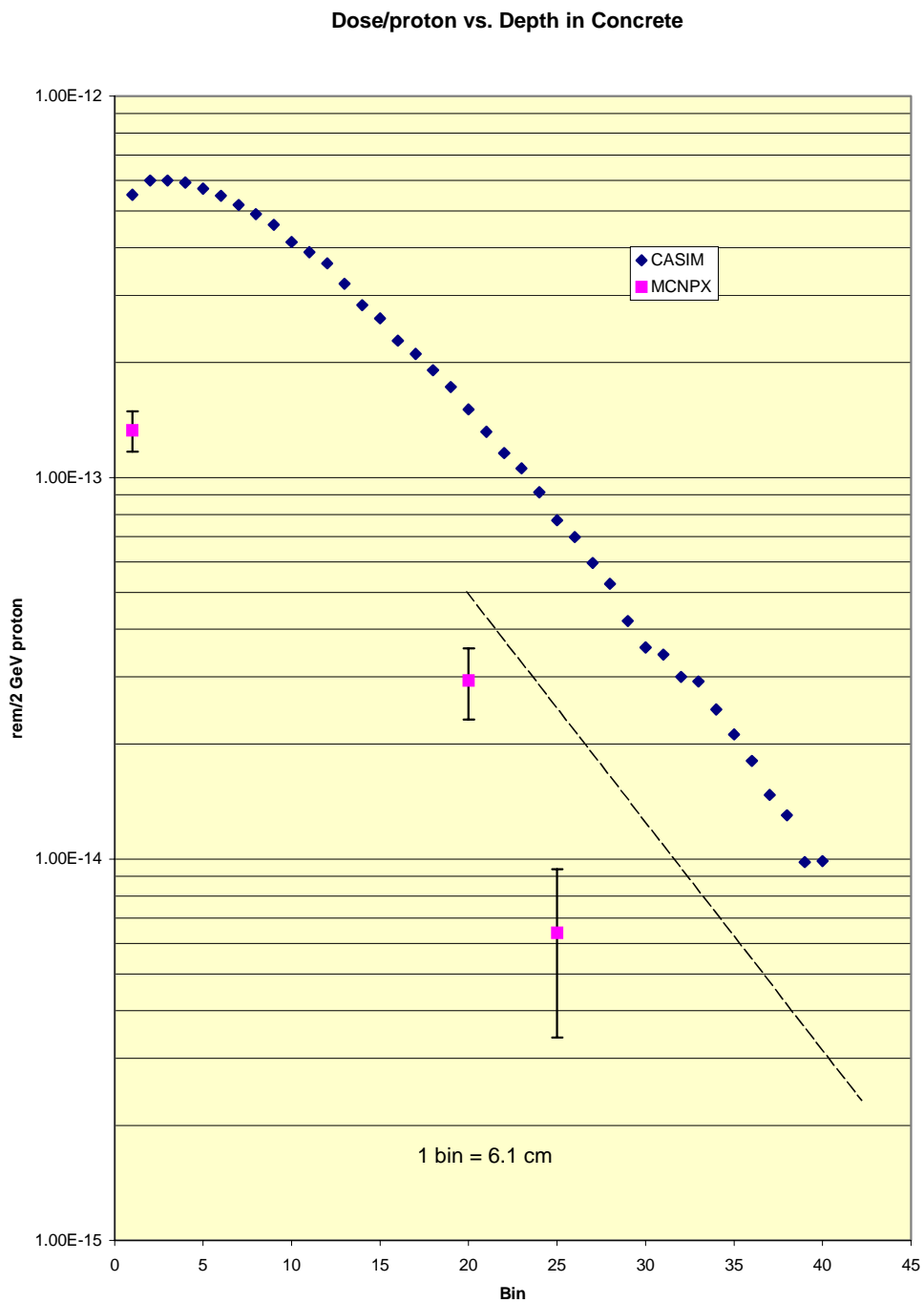


Fig. 10 Dose vs. Distance in Concrete

## BAF SAD Appendix 2

### BROOKHAVEN NATIONAL LABORATORY

#### M E M O R A N D U M

DATE: Thursday, September 04, 1997

TO: W. McGahern

FROM: E. Lessard

SUBJECT: Initial AGS Design Requirements For BAF

The following assumptions were made:

- 1)  $1 \times 10^{11}$  protons per pulse is maximum beam pulse.
- 2) 5 GeV protons.
- 3) One pulse every 3 seconds.
- 4) One hour of continuous full beam loss.
- 5) 1500 hours per year on the beam stop at full intensity.

Discussions with you, W. Glenn, and K. Reece lead to the following conclusions:

- 1) At least 17 feet of earth, or equivalent, side and roof shielding is needed to reduce fault levels to 5 mrem/h or less for continuous loss of full beam. This allows areas outside BAF to be labeled as Controlled Areas. Thicker shielding should be used around the target hall for ALARA.
  - a) If 13 feet of earth or equivalent is used, then the outside areas near the stop and target hall will be Radiation Areas and fault levels of 35 mrem/h are possible.
- 2) The nearest occupied building, B919 at 300 feet, would receive about 1 mrem per year from skyshine levels of 5 mrem/h outside the shield over a target.
- 3) Forward radiation level ( $0^\circ$ ) at 3 feet from full-beam loss-point is  $1.5 \times 10^7$  mrem/h.
  - a) Attenuation needed through labyrinth opening placed after target is about  $3 \times 10^{-7}$  in order to reduce to a Controlled Area at the labyrinth entrance leading to target cave.
- 4) Lateral radiation level ( $90^\circ$ ) at 3 feet from full-beam loss-point is  $3.4 \times 10^5$  mrem/h.
  - a) Attenuation needed through penetrations at beam height is  $2 \times 10^{-5}$  to reduce to a Controlled Area at the outside entrance of penetration. Penetrations that are off beam height need about  $3 \times 10^{-5}$  attenuation.
- 5) Rearward radiation level ( $180^\circ$ ) at 3 feet from full-beam loss-point is  $1 \times 10^5$  mrem/h.
  - a) Attenuation needed in labyrinth opening placed behind target is  $5 \times 10^{-5}$  in order to reduce to a Controlled Area at the entrance leading to target cave.
- 6) The range of 5 GeV protons and muons in iron is about the same and is about 11 feet. Earth could be used as a small part of the proton beam stop length. If earth is used,

then the activation of soil by protons directly must be considered. A tenth value layer in iron is 1.36 feet. Ten feet of iron reduces the protons to  $1.4 \times 10^3$  per pulse. The exact concentrations produced in soil would depend on the beam size at the end of the iron stop. Assuming  $1 \text{ cm}^2$  beam size, a 30 mb cross-section for  $^{22}\text{Na}$  production in soil, a density of  $1.8 \text{ g/cm}^3$ , and effective mass number for soil of 25, I estimate 10 feet of iron would be needed to reduce potential concentrations of  $^{22}\text{Na}$  below the Drinking Water Standard.

- 7) Estimates of earth activation that lead to groundwater contamination lateral to the beam stop show that the iron beam-stop should have a thickness from beam center to outer lateral edge of at least 4.5 feet. This ensures that potential ground water contamination would be 5 times less than the Drinking Water Standard for  $^{22}\text{Na}$  lateral to the stop.
- 8) A plastic liner or kevlar sheet should be placed in the soil above all beam loss-points. A liner similar to that used at the Booster is thought to be appropriate. This includes the iron beam-stop, the collimators if any, and the target.
- 9) If significant beam loss occurs at the target or collimators, then shielding near these locations should be such that nearby rainwater in soil is not activated above the Drinking Water Standard.
- 10) Closed water-systems and re-circulating air-systems should be designed into the target area and beam line.
- 11) Sumps that can hold 30% of the volume of water in the cooling system should be incorporated into the facility. Floor drains leading directly to the ground or to sanitary should be avoided.

Copy to:

J. W. Glenn  
T. Kirk  
D. Lowenstein  
A. McNerney  
P. Pile  
A. Pendzick  
K. Reece



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managed by Brookhaven Science Associates  
for the U.S. Department of Energy

*date:* Thursday, December 21, 2000 (Revised 6/8/01)

*to:* Distribution

*from:* E. T. Lessard

*subject:* BAF High-Energy Particle Maximums Assumed for the SAD

## Memo

Based on discussions on December 12, 2000 and the attached prescription by R. Prigl, the following assumptions are established in order to bound analyses in the BAF Safety Assessment Document. These bounds indirectly set the radiological controls for the facility. Other factors that influence radiological controls are thickness of shield, occupancy and fencing. These other factors plus the bounds assumed here will provide details that allow a safety analyses specific to BAF to go forward.

### Routine Operations with High-Energy Particles

#### Maximum Annual High-Energy Flux from Booster Slow Extracted Beam (SEB) System

- The annual limit on the number and kinetic energy of high-energy nucleons extracted from the Booster SEB system is stated in terms of the product of nucleon energy and nucleon flux and shall be no greater than  $10^{17}$  GeV in one year.
- No more than 30% of the annual limit on the number and kinetic energy of nucleons extracted from the Booster SEB shall enter the BAF.

#### Maximum Hourly High-Energy Flux from Booster SEB

- The hourly limit on the number and kinetic energy of high-energy nucleons extracted from the Booster SEB system is stated in terms of the product of nucleon energy and the nucleon flux and shall be no greater than  $6 \times 10^{14}$  GeV in one hour.
- 100% of the hourly limit on the number and kinetic energy of nucleons extracted from Booster SEB may enter the BAF.

#### Maximum High-Energy Flux on the BAF Beam Stop

- The maximum annual high-energy flux on the BAF beam stop shall equal 30% of the maximum annual high-energy flux from Booster SEB.
- 100% of the hourly limit on the number and kinetic energy of nucleons extracted from Booster SEB may enter the BAF beam stop.

## Maximum High-Energy Flux on BAF Targets

- The maximum annual high-energy flux on BAF targets shall equal 100% of the maximum annual high-energy flux on the BAF beam stop. The targets are assumed to be 0.25 nuclear interaction lengths.
- 100% of the hourly limit on the number and kinetic energy of nucleons extracted from Booster SEB may be stopped at BAF targets. The targets are assumed to be 1.0 nuclear interaction length.

## Summary of Routine Operating Scheme for Booster Applications Facility

Quantity	Maximum Value
Annual Energy Flux from Booster SEB	$10^{17}$ GeV in one year
Hourly Energy Flux from Booster SEB	$6 \times 10^{14}$ GeV in one hour
Annual Energy Flux on the BAF Beam Stop	$3 \times 10^{16}$ GeV in one year
Hourly Energy Flux on the BAF Beam Stop	$6 \times 10^{14}$ GeV in one hour
Annual Energy Flux on BAF Targets (0.25 nuclear interaction lengths)	$3 \times 10^{16}$ GeV in one year
Hourly Energy Flux on BAF Targets (1.0 nuclear interaction length)	$6 \times 10^{14}$ GeV in one hour

Fault with High-Energy Particles

The maximum, single event, non-routine point loss shall be  $1.5 \times 10^{14}$  5-GeV nucleons per second for 9 seconds.<sup>1</sup> Nine seconds is the assumed response time of fixed-area radiation monitors to interlock the beam. That is, a single-event, high-energy nucleon loss of  $6.75 \times 10^{15}$  GeV shall be the maximum fault assumption for any location in the BAF.

\*   \*   \*

## Distribution:

Beavis, D.  
 Etkin, A.  
 Karol, R.  
 Prigl, R.  
 Rusik, A.  
 Stevens, A.

## Copy to:

McNerney, A.  
 Sutherland, B.  
 Vazquez, M.

## Attachment:

An Estimate of the Annual Beam for BAF, R. Prigl, 12/12/00

---

<sup>1</sup> Conceptual Design Report, Booster Applications Facility, October 1997.

## An Estimate of the Annual Beam for BAF

The Booster Application Facility (BAF) will provide beams of protons and heavy ions to a large user community with a variety of beam intensity and beam energy requirements. Since detailed running plans are not available at this time, the expected annual beam will be estimated based on the May 1999 run for NASA experiment E947, a run with a spectrum of users similar to what is expected for BAF operation. For this experiment, the AGS accelerated  $7.2 \times 10^{13}$   $^{56}\text{Fe}$  Ions or  $4.0 \times 10^{15}$  nucleons total to an energy of 1 GeV/nucleon over 150 hours of beam time. For BAF operations we assume that about the same number of nucleons will be accelerated in the Booster for extraction to the BAF beam line per hour of operation. With 1500 hrs of running time per year this translates to an expected  $4 \times 10^{16}$  nucleons accelerated annually for BAF. The maximum energy per nucleon that can be extracted into the BAF beam line is 3.07 GeV for protons and half of that or less for any heavy ion species. For Fe the maximum energy is 1.1 GeV/nucleon. For estimates of radiological quantities associated with BAF we assume an annual beam of  $1 \times 10^{17}$  GeV-nucleons.

For comparison, we can estimate the number of nucleons that the Booster is able to accelerate for Fe. The maximum intensity (see BAF-CDF) for this species is  $0.4 \times 10^9$  Ions or  $2.2 \times 10^{10}$  nucleons per Booster cycle. Assuming a typical cycle time of 2.5 seconds, this translates into the same  $4 \times 10^{16}$  nucleons for 1500 hours. The maximum intensity per cycle is reduced relative to running NASA at the AGS because for BAF operations the Booster will accelerate  $\text{Fe}^{21+}$  instead of  $\text{Fe}^{10+}$ , which requires an additional stripping foil near Booster injection. This is more than compensated by the use of a pair of octupole magnets in the BAF beam line, which will provide a flat beam profile without the need of heavy beam collimation. Given that many of the NASA experiments require short exposures and frequent changes of samples the accelerator is usually idle for more than 50% of the time and therefore our estimate of  $1 \times 10^{17}$  GeV-nucleons annually is conservative both in the number of nucleons and in the energy per nucleon.

Most of the experiments will require lower beam intensities, typically by a factor of 10 or more, than the accelerator can provide. We expect that the intensity will be reduced by closing the collimator at the D6 BAF extraction septum rather than by reducing the beam intensity in the Booster. Therefore, we generally assume that on average 90% of the accelerated beam will be lost at the extraction septum including its collimator. For estimates of radiation levels along the BAF beam line, near the target room and beam stop we assume that on average 30% of the accelerated beam will be transported to the BAF target room.

## BAF SAD Appendix 4

### FACILITY/PROCESS RADIONUCLIDE NESHAPs EVALUATION

Prepared by  
G. Schroeder  
January 4, 2001

#### 1. SOURCE NAME AND LOCATION

Name(s): Booster Applications Facility  
Location: North of Bldg. 914, W. Fifth Ave.  
Brookhaven National Laboratory  
Upton, New York 11973  
Latitude: N 40° 52'  
Longitude: W 72° 53'

The Booster Applications Facility will be located at Brookhaven National Laboratory. BNL is a multidisciplinary scientific research center located close to the geographic center of Suffolk County on Long Island, about 97 km east of New York City. About 1.4 million persons reside in Suffolk County and approximately 0.41 million persons reside in Brookhaven Township, the municipality within which the Laboratory is situated.

#### 2. RELEASE POINT INFORMATION

Location: Booster Applications Facility Target Room  
Stack height (m): 7.6  
Stack Diameter (m): 0.3  
Exhaust velocity (m/sec): 4.6  
Exhaust temp. (°F): ambient

#### 3. TECHNICAL INFORMATION ABOUT THE SOURCE

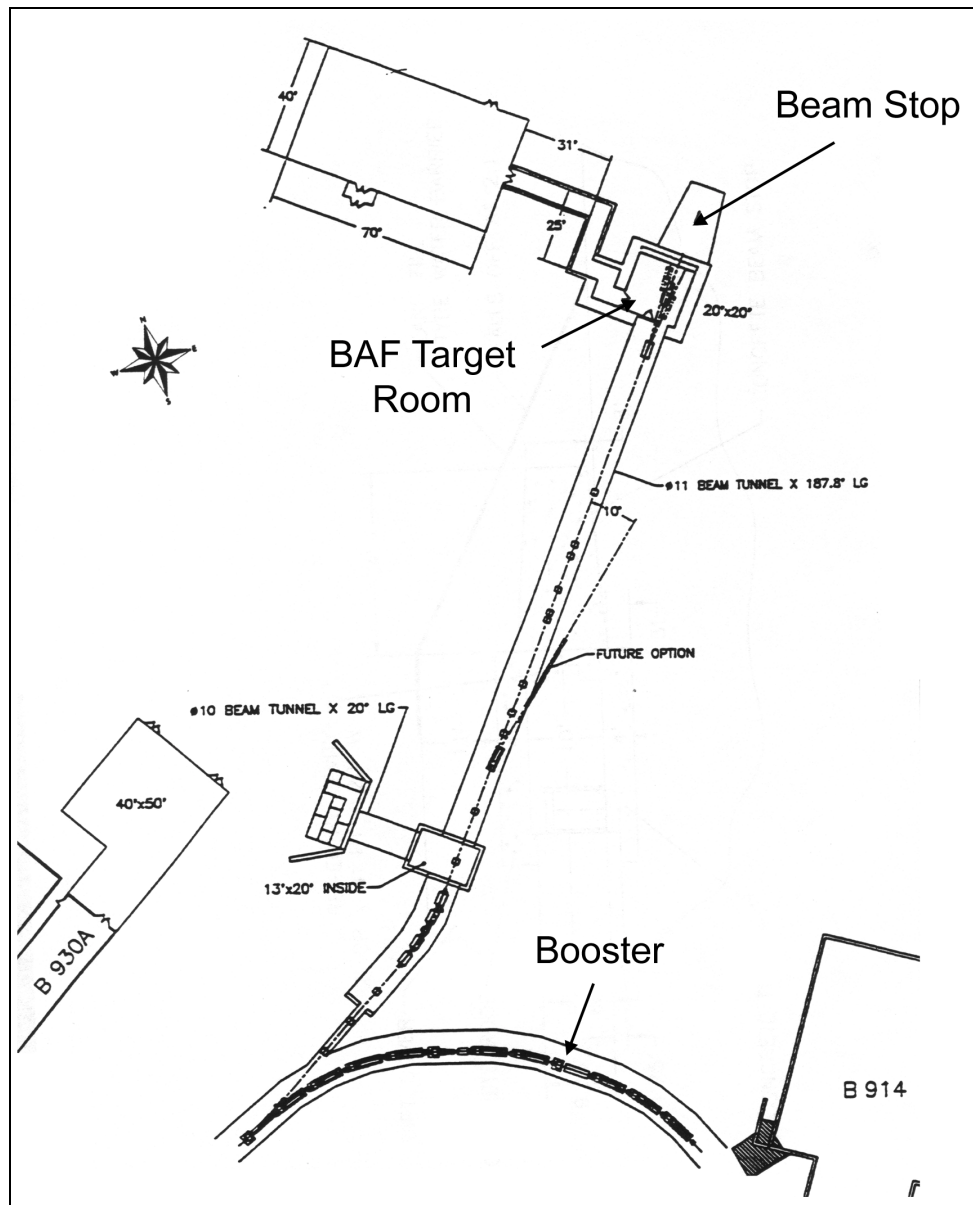
##### A. Overview of Operations

The Department of Energy, the National Aeronautical and Space Administration and the Department of Defense have identified a need for the creation of a research facility that could conduct space radiation research. Simulation of space radiation effects requires the capability to produce protons and electrons at relatively low energies, and heavy and light ions at energies in the GeV per nucleon range. In response to a July 1992 Memorandum of Understanding between NASA and the DOE and a subsequent agreement between NASA and Brookhaven National Laboratory, a high energy, heavy ion irradiation facility is to be constructed at the BNL site. This facility is will use a beam line diverted from the existing Alternating Gradient Synchrotron (AGS) Booster facility.

The AGS Booster is a circular accelerator with a circumference of nearly 200 m, and is connected to the northwest portion of the main AGS ring and the LINAC (see Figure 1). The Booster, which has been in operation since 1994, receives either a proton beam from the LINAC or heavy ions from the Tandem Van de Graaff. The Booster accelerates protons and heavy ions prior to injection into the main AGS ring.

## BAF SAD Appendix 4

The BAF will consist of a new beam tunnel branching from the AGS Booster ring, a target room and beam stop, and a number of associated support buildings. The facility will receive a proton beam from the AGS Booster. Once the beam is diverted out of the Booster, it will travel through a 27 m beam line tunnel where it will be diverted 20 degrees. The beam will then be directed down a 80 m long beam line tunnel where it will enter the BAF target room. Secondary radiation fields in the target room will generate air activation products which have the potential to exit the building and be released to the atmosphere.

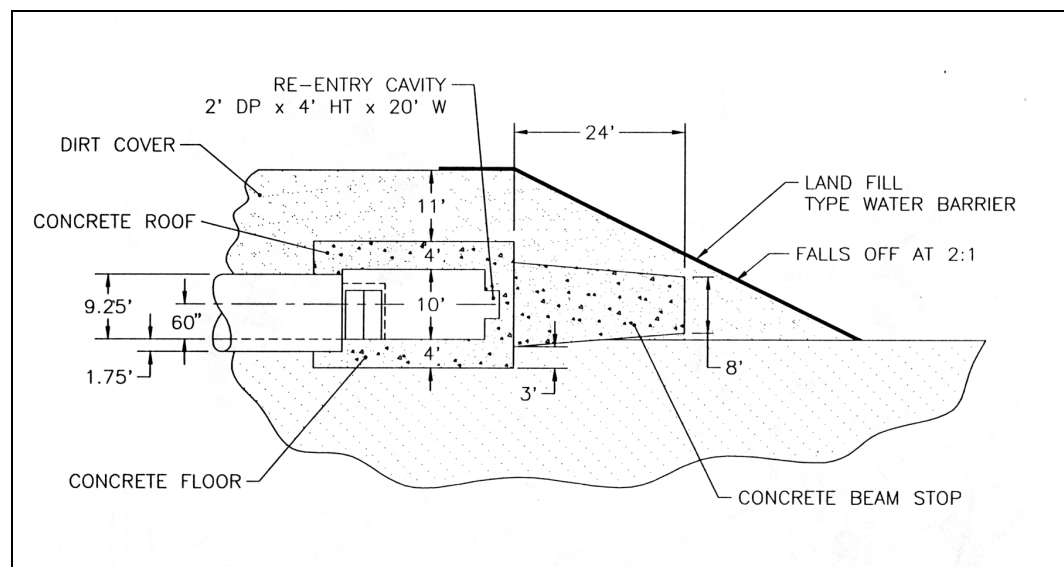


**Figure 1 Location of Booster Applications Facility.**

## BAF SAD Appendix 4

### B. Ventilation System Description

The target room will be ventilated as part of standard building HVAC and to reduce animal odors. Room air will be ventilated via an exhaust point on top of an external berm covering the room (see Figure 2). The exit point will be approximately 7.6 m above ground level. The duct leading to the exhaust point is 0.3 m in diameter, constructed of stainless steel. The exhaust fan will have a volumetric exhaust rate of 535 CFM, and an exit velocity of 4.6 m/sec. The exhaust point will be covered with a "mushroom" type rain cap, which will serve to redirect the exhaust downward, towards the roof. However, for purposes of this evaluation, it will be conservatively assumed that no such cap exists and that the contents of the exhaust are free to be upwardly lofted by vertical momentum.



**Figure 2 Side view of BAF target area.**

### C. Source Term Development

The air activation estimate was made by A. Stevens using the MCNPX computer model (see the BAF Safety Assessment Document, Chapter 4 for additional details). The vacuum pipe will terminate 1.5 m upstream of the target room, making the beam path length in air 8.5 m (including the length of the re-entrant dump cavity). With a correction for the target thickness, the room-averaged hadron flux  $> 20$  MeV from interactions becomes  $2.1 \times 10^{-6}$  per  $\text{cm}^2$  per incident 2 GeV proton, and the thermal neutron flux is  $3.4 \times 10^{-6}$  per  $\text{cm}^2$  per proton. However, the room-averaged flux of the incident beam particles is  $6.8 \times 10^{-6}$  per  $\text{cm}^2$  per proton, dominating the activation. Assuming  $3 \times 10^{16}$  GeV of total deposited energy per year, the following source terms result:

## BAF SAD Appendix 4

Table 1. BAF Annual Air Activation Product Source Terms

Radionuclide	Ci/yr
Ar-41	2.6E-3
S-35	1.6E-7
P-32	1.0E-6
Al-28	8.1E-5
Na-22	6.3E-9
O-15	7.4E-1
O-14	3.2E-2
N-13	1.8E-1
C-11	8.1E-2
Be-7	2.1E-5
H-3	8.8E-7

### D. Dose Assessment

The radiological dose impact to the maximally exposed individual (MEI) has been estimated using the Clean Air Act Code CAP88-PC. A site-specific model was utilized with 10-year average meteorology (wind rose, temperature, and precipitation) and the most current population data. Note that the CAP88-PC model is explicitly designed to model airborne continuous radioactive emissions, which occur over the course of a single year. It is not to be used to estimate short-term or acute releases. Given this limitation, this evaluation treats this potential emission source as if it is a continuous annual source. Note also that aluminum-28 and oxygen-14 are not included in the CAP88-PC radionuclide library and could not be modeled. However, the source terms and half-lives of these radionuclides is so small that their exclusion does not significantly affect the conclusions of this evaluation.

The cover sheet of the CAP88-PC summary report (attached) indicates that the dose to an individual at the northeastern boundary is 9.7E-6 mrem/yr. The dose to the MEI is far below the 10 mrem/yr annual limit specified in 40 CFR 61, Subpart H, and below the 0.1 mrem/yr limit which triggers the NESHAPs permitting process. Therefore, no application is required for the Booster Applications Facility.

# BAF SAD Appendix 4

C A P 8 8 - P C

Version 2.00

Clean Air Act Assessment Package - 1988

## S Y N O P S I S   R E P O R T

Non-Radon Population Assessment

Jan 4, 2001 03:31 pm

Facility: Booster Applications Facility  
Address: Brookhaven National Laboratory  
West Fifth Avenue  
City: Upton  
State: NY                      Zip: 11973

Source Category: point  
Source Type: Stack  
Emission Year: 2001

Comments: Booster Applications Facility annual emissions  
off-site dose estimate.

Effective Dose Equivalent  
(mrem/year)

---

9.70E-06

---

At This Location:    2000 Meters Southwest

Dataset Name: BAF  
Dataset Date: Jan 4, 2001 03:28 pm  
Wind File: C:\CAP88PC2\WNDFILES\BNL8089A.WND  
Population File: C:\CAP88PC2\POPFILES\BNL98A.POP

## BAF SAD Appendix 5

### C-A Unreviewed Safety Issue (USI) Form

Title of USI: New Booster Dump and New Slow Extraction Components for Booster to BAF

Description of USI (use attachments if necessary):

With regard to the new Booster dump, the dump design, planned losses, induced activity in soil, shielding, cap design and limiting conditions for operations remain unchanged. There are no changes in electrical hazards, fire hazards, radiation hazards or changes to relevant protection systems for the Booster. Only the location of the dump in the Booster Ring is changed and a new cap is installed in the earth shield above it. The dump is moved from D section to B section. See attached.

With regard to major new slow-extraction components, a thin septum magnet, thick septum magnet, stripper foil and collimator are inserted in the space freed up by moving the beam dump from D section. A 13-inch pipe has been inserted through the earth-berm at D section to allow extraction of beam into the BAF tunnel. There are no changes in electrical hazards, fire hazards, radiation hazards or changes to relevant protection systems for the Booster. See attached.

It is noted that the existing Booster earth shield and cap were designed for a planned annual beam loss in the D section of  $2.9 \times 10^{19}$  nucleons at 1.5 GeV (Booster FSAR, page 68) or equivalent ( $4.3 \times 10^{19}$  GeV). This planned loss was due to the presence of a dump. As indicated in Appendix 3 of the BAF SAD,  $7 \times 10^{16}$  GeV from high-energy nucleons is the planned annual loss, which is 0.16 % of the design loss for this location in Booster. Thus, the new extraction equipment is adequately shielded for protection against radiation and the area is adequately capped for protection of groundwater.

Title and Date of Relevant SAD: Booster Final Safety Analysis Report, 1991

<http://www.rhichome.bnl.gov/AGS/Accel/SND/BoosterSAD/BOOSTER.PDF>

**Committee Chair or ESHQ Division Head must initial all items. Leave no blanks:**

ITEM	APPLIES	DOES NOT APPLY
Decision to not revise the current SAD and/or ASE at this time.	ETL	
The hazard associated with the proposed work or event is covered within an existing SAD and/or ASE.	ETL	
SAD Title and Date: <b>Booster Final Safety Analysis Report, 1991</b>	ETL	
This Form and attachments, if necessary, shall be used to document the USI until the next revision of the appropriate SAD.	ETL	
Decision to submit a revised SAD and/or ASE to the BNL ESH Committee.		ETL
The hazard associated with the proposed work is not appropriately included in an SAD.		ETL

Ray Kurof  
Signature of C-A Committee Chair or C-A ESHQ Division Head

5-8-01  
Date

Edward T. Ressand  
Signature of C-A Associate Chair for ESHQ

5-8-01  
Date

USI: New Booster Dump and New Slow Extraction Components for Booster to BAF

Specific Changes to the Booster Final Safety Analysis Report

Replace Old Section:

2.4.6 Beam Dump and Catcher

In order to dispose of the beam during studies and aborts, a beam dump system consisting of a dump kicker and an absorber block is provided as shown in Figure 12.7. The beam dump is a 1 m long steel cylinder surrounding the beam pipe. It has a radial thickness of 19 cm. It is shielded by an additional 20 cm of iron in order to reduce the activation of nearby soil outside the tunnel enclosure. A movable lead curtain slides from an area where activation is slight to form a wall around the dump in order to eliminate personnel exposure from the residual radiation residual radiation. The Incoloy steel cylinder has a 2.54 cm lip interior to the vacuum chamber which is, by design, the limiting aperture: for the Booster, and thus serves to catch the beam losses during injection and acceleration.

With New Section:

2.4.6 Beam Dump and Catcher

In order to dispose of the beam during studies and aborts, a beam dump system consisting of a dump kicker and an absorber block is provided. The location of the beam dump is in the B section and is shown in the attached Figures 1 and 2. The beam dump is a 1 m long steel cylinder surrounding the beam pipe. It has a radial thickness of 19 cm. It is shielded by an additional 20 cm of iron in order to reduce the activation of nearby soil outside the tunnel enclosure. Time, distance and shielding are used during maintenance periods in order to reduce personnel exposure from residual radiation from the dump. The Incoloy steel cylinder has a 2.54 cm lip interior to the vacuum chamber that is, by design, the limiting aperture: for the Booster, and thus serves to catch the beam losses during injection and acceleration.

An impermeable cap to prevent rainwater from entering activated soil near the beam dump has been installed above the dump kicker in B section. The cap is similar in design to the existing cap used for the dump formerly positioned at the D section. The cap at the D section remains in place undisturbed and is overlapped by the cap for the BAF tunnel.

Add Section:

2.4.4.1 Slow Extraction at the Booster

The Booster has operated since 1991 as an injector of protons and heavy ions into the AGS. In order to deliver an external slow extracted beam to the Booster Applications Facility, new equipment was added that rearranges existing apparatus.

## BAF SAD Appendix 5

### USI: New Booster Dump and New Slow Extraction Components for Booster to BAF

A thin septum magnet is installed in the D section and is similar in design and in specification to the F5 extraction septum that is used in the AGS but is built to  $10^{-11}$  Torr UHV vacuum standards. A thin 0.76 mm copper septum is used to minimize beam loss. Inconel water lines are brazed to each edge of the septum to cool it.

A thick septum magnet is installed in the D section and is similar in concept to the present F6 extraction septum magnet used for the Booster. The magnet core and the water-cooled copper bus work are located outside of the vacuum. A special "Y" chamber is used with an Inconel chamber for the extracted beam, which fits in the aperture of the magnet. The Booster circulating beam goes in a nickel-plated steel chamber that is welded to the Inconel chamber at the upstream end. This magnet is built with four small conductor windings in the septum and the backleg. This design is also used in the AGS F10 extraction septum magnet that operates DC with similar currents.

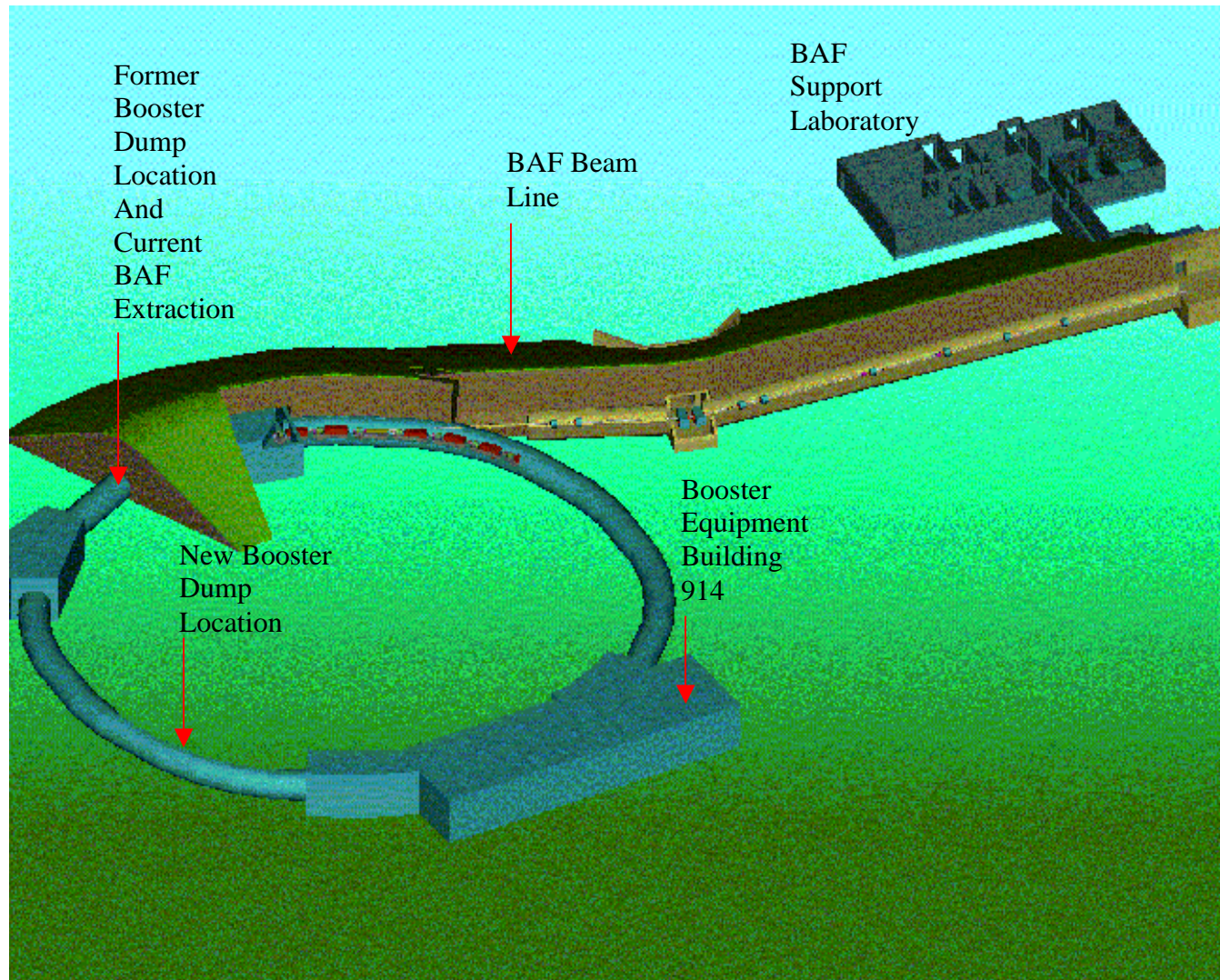
A stripping foil mechanism and a radial single-jaw collimator are upstream of the thick septum magnet. This foil holder/changer is similar in design to the mechanism currently used for Booster H<sup>-</sup> injection.

Power supplies for these components are located in Building 930 upper equipment bay (UEB) and the first floor. Building 930 is a power supply building that was described in the Booster Final Safety Analysis Report. Power distribution remains the same. See attached Figures 3 and 4.

## BAF SAD Appendix 5

USI: New Booster Dump and New Slow Extraction Components for Booster to BAF

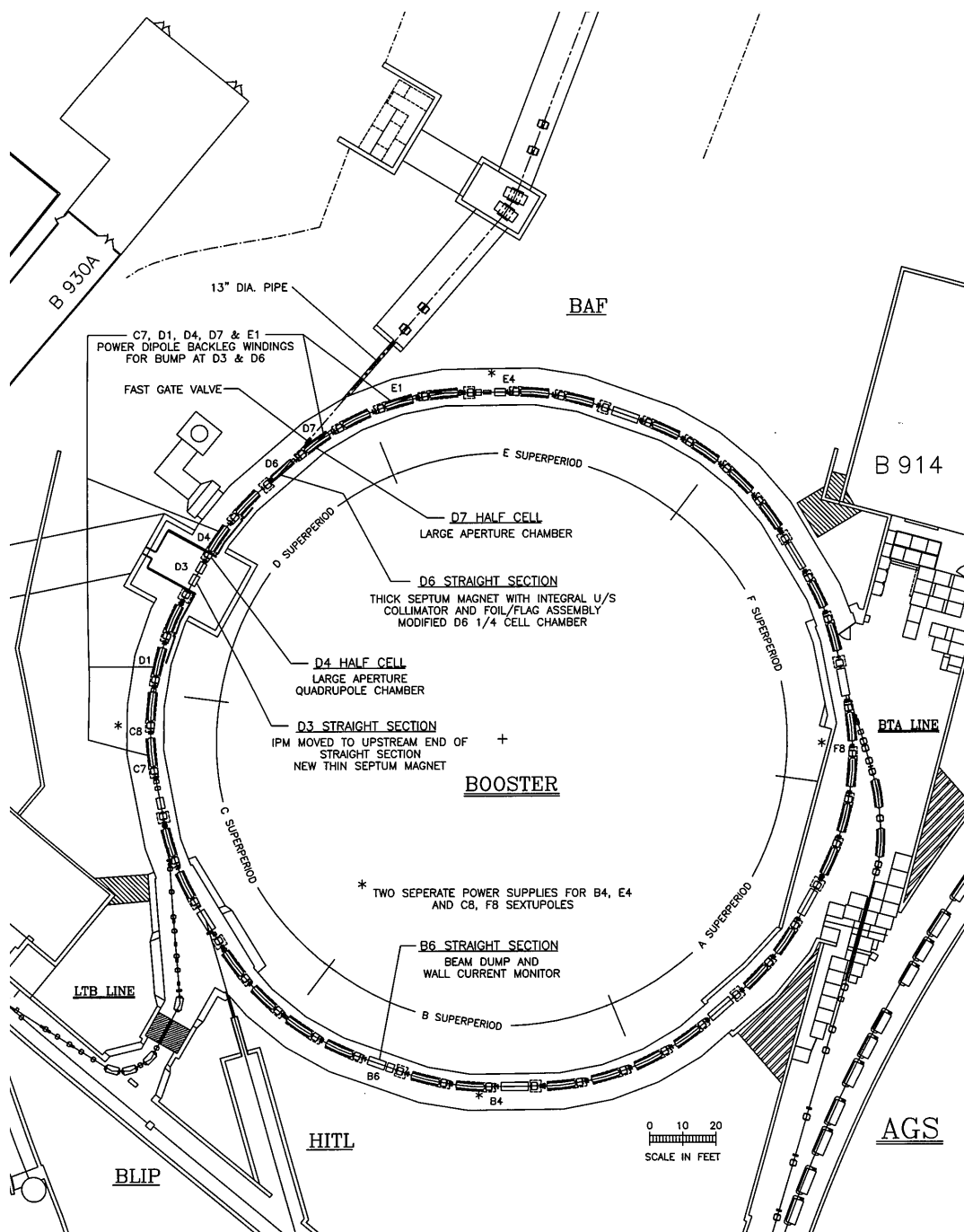
Figure 1 3 D View of Booster Showing BAF Tunnel, BAF Extraction and Booster Dump



## BAF SAD Appendix 5

USI: New Booster Dump and New Slow Extraction Components for Booster to BAF

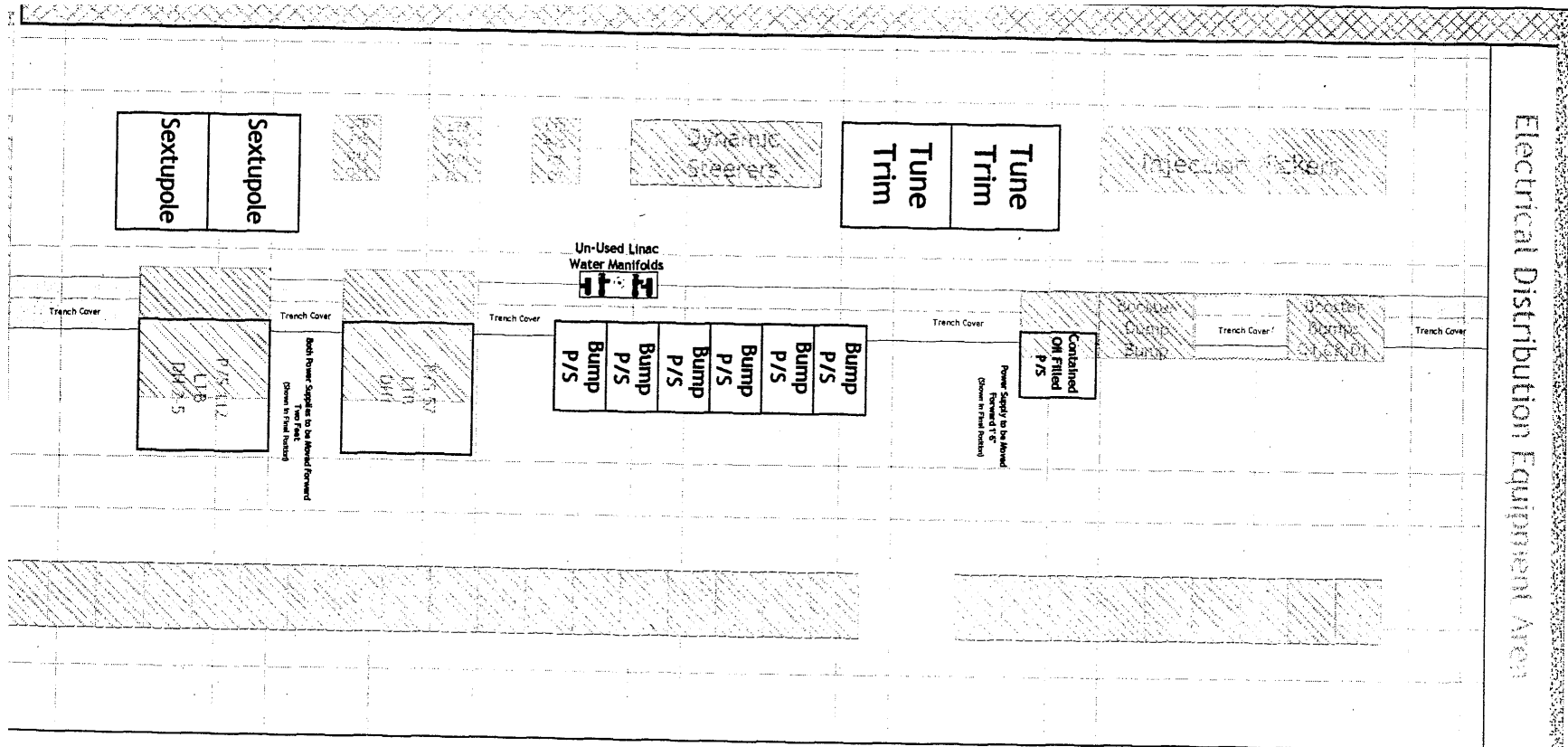
Figure 2 Booster Slow Extraction in D Section and Booster Dump in B Section



BOOSTER APPLICATIONS FACILITY  
MODIFICATIONS FOR EXTRACTION

USI: New Booster Dump and New Slow Extraction Components for Booster to BAF

Figure 3 Location of Power Supplies for Slow Extracted Beam Components in Booster

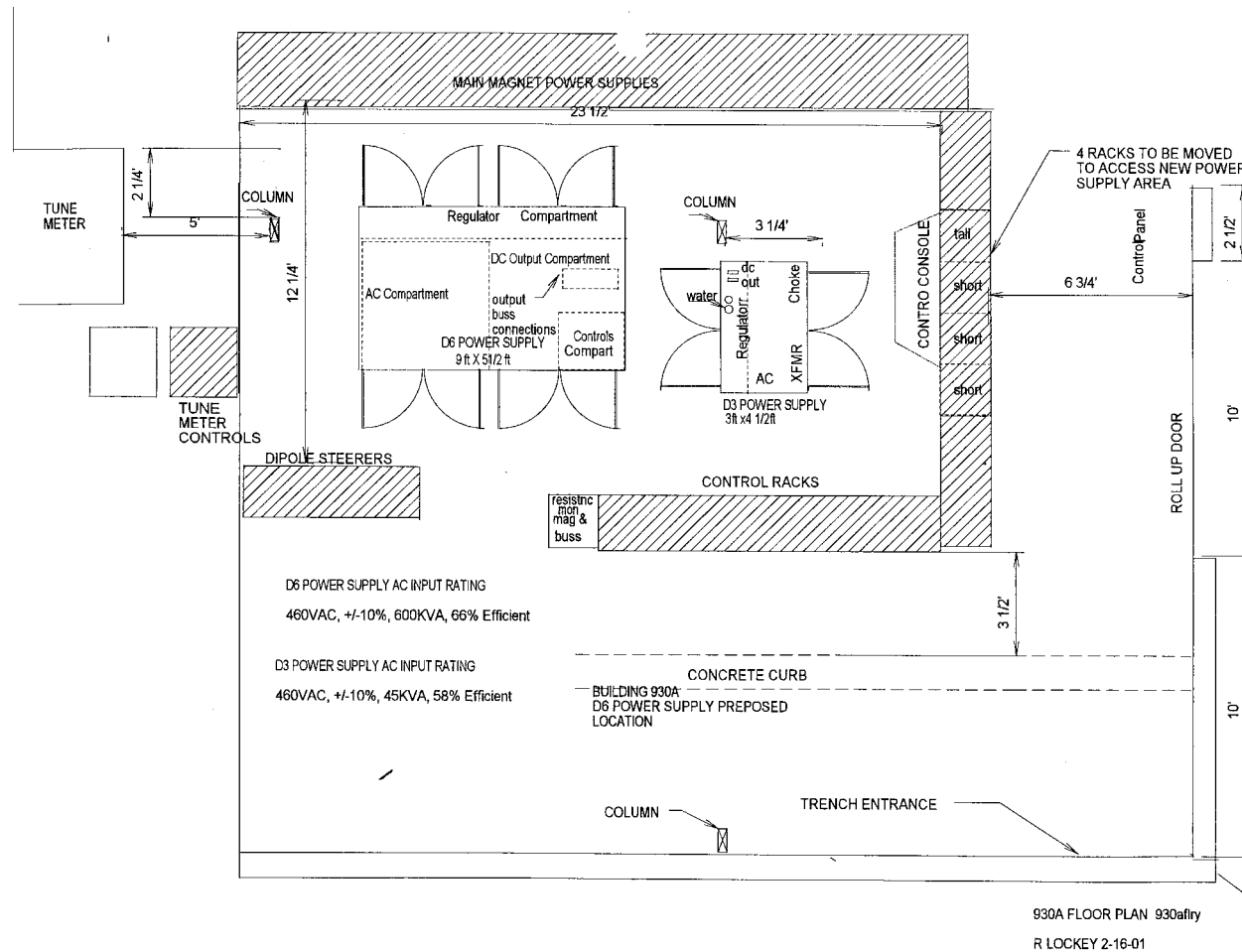


## BAF Equipment Locations in Building 930 UEB

## BAF SAD Appendix 5

### USI: New Booster Dump and New Slow Extraction Components for Booster to BAF

Figure 4 Location of D3 and D6 Power Supplies for Slow Extracted Beam Components in Booster



10CFR835 ALARA Design Document for BAF

Background .....	1
Dose Assessments .....	4
Review of Radiological Conditions versus Trigger Levels .....	4
Identification Of The Applicable Radiological Design Criteria .....	7
Review Of Previous Similar Jobs, Designs And Processes That Have Similar Hazards ...	8
Features To Reduce Dose And The Spread Of Radioactive Materials .....	9
Post-Construction Review Of Effectiveness Of Engineering Features .....	10

Background

From 10CFR835 § 835.1002, Facility Design and Modifications:

*During the design of new facilities or modification of existing facilities, the following objectives shall be adopted:*

- (a) Optimization methods shall be used to assure that occupational exposure is maintained ALARA in developing and justifying facility design and physical controls.*
- (b) The design objective for controlling personnel exposure from external sources of radiation in areas of continuous occupational occupancy (2000 hours per year) shall be to maintain exposure levels below an average of 0.5 mrem (5 microsieverts) per hour and as far below this average as is reasonably achievable. The design objectives for exposure rates for potential exposure to a radiological worker where occupancy differs from the above shall be ALARA and shall not exceed 20 percent of the applicable standards in § 835.202.*
- (c) Regarding the control of airborne radioactive material, the design objective shall be, under normal conditions, to avoid releases to the workplace atmosphere and in any situation, to control the inhalation of such material by workers to levels that are ALARA; confinement and ventilation shall normally be used.*
- (d) The design or modification of a facility and the selection of materials shall include features that facilitate operations, maintenance, decontamination and decommissioning.*

With regard to 10CFR835 § 835.1002 (a), optimization methods are prescribed in [C-A OPM 9.5.6, ALARA Optimization and Cost Benefit](#). The purpose of that procedure is to compare dose savings over the life of a system to the cost of the design, installation and maintenance. Cost-benefit analysis is a technique that helps optimize a given radiation protection practice or it is used to select between proposed practices. The BAF liaison engineer and liaison physicist, with the help of C-A Department ALARA Committee members, perform the analysis. The ALARA Committee Chair may elect to perform a qualitative analysis or a quantitative analysis.

The following considerations are addressed for a qualitative approach to the analysis:

- Identification of the system or component
- Recognition of the affected groups and their needs
- Selection of the alternatives to be evaluated
- Decision to select from the available alternatives

As an option, an analysis may be used for a quantitative cost-benefit determination. If selected as the optimization method, then a calculation of collective dose for the operation over the time under consideration must be made. The dose may be based on archival reports, operation and maintenance histories, survey results, occupancy and other relevant data. The computation of collective dose is as follows:

$$(\text{Person-rem/job}) (\text{Jobs/year}) (\text{Years}) = \text{Collective Dose}$$

One must calculate the collective dose for the same period considering the alternative that employs a dose-reduction option. The alternative also may be justified if it can enhance system safety or reliability. If a reasonable alternative does not exist, a quantitative cost-benefit analysis is not warranted.

For quantitative analysis, one evaluates the cost of each alternative in terms of:

- Manpower requirements
- Design and engineering cost
- Operating and maintenance cost
- Retirement and disposal cost
- Radiation exposure to implement the alternative, to maintain and operate the system or component and to dispose of equipment and facilities

For purposes of quantitative cost-benefit analysis, a value of \$11,000 per person-rem is used by the C-A Department. For each alternative, one obtains the product of collective dose and \$11,000/person-rem. The monetary value of \$11,000 per person-rem is based on a monetary value used by nuclear power plants in the United States to assist in management decisions regarding dose reduction plant modifications or equipment investments.<sup>1</sup> One compares this monetary value with the cost of the alternative. After all costs are determined, political, social and programmatic factors are considered. Based on cost-benefit analysis and the other factors, one selects the appropriate alternative.

With regard to 10CFR835 § 835.1002 (b), the design objective for controlling personnel exposure from external sources of radiation in areas of continuous occupancy, 2000 hours per year, is to maintain exposure levels below an average of 0.5 mrem per hour and as far below this average as is reasonably achievable. The design objective for exposure rates where occupancy is not continuous is ALARA and does not exceed 1 rem per year. See [C-A OPM 9.1.12 Procedure for Review of C-A Shielding Design](#).

With regard to 10CFR835 § 835.1002 (c), the design objective for BAF for the control of airborne radioactive material is to avoid releases to the workplace atmosphere and to control the inhalation of such material by workers to levels that are ALARA; and to use confinement and ventilation. See [C-A OPM, 9.5.2 ALARA Design Review](#).

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<sup>1</sup> North American ALARA Center, College of Engineering, University of Illinois,  
[http://hps.ne.uiuc.edu/isoedata/html/Dollars\\_per\\_Person\\_REM\\_Saved.htm](http://hps.ne.uiuc.edu/isoedata/html/Dollars_per_Person_REM_Saved.htm)

With regard to 10CFR835 § 835.1002 (d), the design of BAF and the selection of materials include features that facilitate operations, maintenance, decontamination and decommissioning. See [C-A 9.5.4.e, Summary of C-A ALARA Practices](#).

From Section IV, Subsection H, DOE G 441.1-2, "Occupational ALARA Program Guide for use with Title 10, Code of Federal Regulations, Part 835, Occupational Radiation Protection:"

The level of effort involved in documenting ALARA decisions should be commensurate with the potential dose savings to be realized. A detailed evaluation need not be made if its cost, including the cost of documentation, outweighs the potential value of the benefits. The procedure used to evaluate the "appropriateness" of dose-reduction and contamination minimization decisions should be maintained. The RCS and PNL-6577 provide additional guidance on optimization methodologies.

From Section IV, Subsection I:

The ALARA design review should have six discrete phases:

1. Dose assessment.
2. Review of radiological conditions against the trigger levels established by management, e.g., creation of a new radiation source or an increase in the dose rates from an existing source; increased operations, maintenance, production, research, inspection or decommissioning requirements in a radiological control area; projected expenditure of a collective dose of greater than 1,000 mrem.
3. Identification of the applicable radiological design criteria.
4. Review of previous similar jobs, designs and processes that have similar hazards to assist in the selection of design alternatives and selection of optimum alternatives using approved optimization methods for evaluating the various ALARA considerations.
5. Incorporation and documentation in the design package of features to reduce dose and the spread of radioactive materials.
6. Post-construction reviews of effectiveness of engineering features to reduce dose and the spread of radioactive materials to provide feedback to the design engineers and help refine the design process.

The procedure describing the process of ALARA design review, including the results of dose assessments, the review of ALARA criteria, the optimization/cost-benefit analysis records, and the recommendations on features to reduce dose and radioactive contamination has been approved by management of the Collider-Accelerator Department and BNL. See C-A OPM, Chapter 9 and SBMS Subject Area, Accelerator Safety.

The ALARA design review record is part of this document and is included such that the records are readily retrievable. Radiological design considerations are discussed in C-A OPM 9.5.2, ALARA Design Review and SBMS, Design Practice for Known Beam Loss Locations.

### Six Discrete Phases of ALARA Design Review for BAF

#### Dose Assessments

Maximum annual dose to a BAF User (experimenter) occupying the Support Laboratory 1500 hours per year is 10 mrem. The maximum dose point is the mouth of the labyrinth leading to the Target Hall.<sup>2</sup> Occupancy is expected to average about 4 to 5 people for 1500 hours per year. The maximum estimated collective-dose to Users in the Support Labs is about 50 person-mrem per year.

The estimated doses<sup>2</sup> from skyshine at the closest occupied non-BAF facilities are:

- 0.27 mrem per year at Building 919, which is a C-AD beam-line component assembly-area, and occupancy is 2000 hours per year by 3 to 4 people.
- 0.0013 mrem per year at Building 931A (BLIP), and occupancy is part time by 1 to 3 people.

The collective-dose from BAF operation is negligible.

Dose from airborne radioactive emissions at site boundary is 0.00001 mrem per year.<sup>3</sup> The collective-dose is negligible.

Dose to Users in the Target Hall from beam-stop gamma-shine is taken as the product of four factors:

- 1) The steady-state dose rate at 1 meter from short-lived activation, 16 mrem/h.<sup>4</sup>
- 2) 22.5% single-person occupancy, which is the percentage operation time assumed to be needed to place targets at the target station.
- 3) 1500 hours of operation per year.
- 4) A factor to correct for distance.

The percentage occupancy was based on one person for 30 seconds every 5 minutes to change samples and two persons for 15 minutes every 4 hours to set up a new set of experiments. The distance from the re-entrant cavity to the target station is about 3 m. Assuming a volumetric cylindrical source of activation products and assuming Users stand 2 m from the face of the re-entrant cavity leading to the beam stop, then the unshielded collective-dose estimate is about 650 person-mrem per year, or a cost of \$7,200 per year. A 2-inch thick iron shield at the face of the re-entrant cavity would reduce this collective dose estimate by about a factor of four to 170 person-mrem per year.

#### Review of Radiological Conditions versus Trigger Levels

There are no ALARA trigger levels for instantaneous or short-term incremental quantities for dose-equivalent rate in units of mrem/h or mrem-in-one-hour, respectively since exposure at C-A facilities is not due to continuous level sources of radiation. Instead, C-

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<sup>2</sup> BAF SAD Appendix 1. Dose point is entrance to labyrinth leading to Target Hall.

<sup>3</sup> BAF SAD Appendix 4.

<sup>4</sup> BAF SAD Appendix 7.

A Department ALARA design triggers are in terms of collective dose to persons, which is impacted by factors such as distance from the source and occupancy time.

In addition, there are radiological triggers that are related to ALARA design review but are not in themselves related to the level of radiation protection. For example, triggers used solely to gain public acceptance dominate the ALARA design review for activated soil, but the costs for capping activated soil to prevent rainwater infiltration are not part of a cost-benefit analyses for radiological protection. That is, a water repellant cap along the entire length of the BAF tunnel is required based on a trigger of potentially exceeding 5% of the Drinking Water Standard in groundwater regardless of the cost of capping. The cap will likely prevent any contamination of the aquifer. However, no radiological dose to people is expected if a cap is not installed and contamination occurs. This is because drinking water supply wells are too distant from the source.

The Collider-Accelerator Department has the following four collective-dose levels that trigger a formal ALARA design review by the C-A ALARA Committee:<sup>5</sup>

- Installation of a new accelerator system, experiment, or beam-line component expected to result in > 750 person-mrem collective exposure.
- Operation of a beam-line component, experiment or accelerator system during its lifetime expected to result in > 750 person-mrem/year averaged over a two-year period.
- Future routine maintenance of a new beam-line component, experiment or accelerator system expected to result in > 0.75 person-rem/year averaged over a two-year period.
- Replacement, removal or rebuilding an existing beam-line component or accelerator system expected to result in > 0.75 person-rem/upgrade.

Collective-dose to Users in the Support Laboratories and the Target Hall, collective-dose to occupants at nearby facilities, and collective-dose to persons at the site boundary do not meet any of these triggers. While not meeting a trigger, the potential dose to Users in the Target Hall from beam-stop gamma-shine was judged to require further study, hence Appendix 7 was developed and the following statements further document a specific cost-benefit analysis for shielding out the gamma-shine from the beam stop.

In the ALARA design review process at C-A Department, the need for further study is generally obvious and the focus is normally on possible design options that have different implications for protection, cost and other factors. The performances of the options are usually predicted together with the operational implications. We note, for example, the number of legs to the labyrinth was optimal; that is, more legs or fewer legs produced higher dose estimates. With regard to the Target Room roof shield, the thickness of concrete was based on soil activation considerations. However, the combined concrete and soil layers of the Target Room roof were based on several factors including steepness of the berm and sky-shine dose estimates. With regard to beam path in air in the Target Room, programmatic needs were considered in optimizing the length of the vacuum pipe.

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<sup>5</sup> C-AD OPM 9.5.2, ALARA Design Review.

## BAF SAD Appendix 6

In the case of exposure of Users to residual radiation from the BAF beam stop, cost, protection and other factors were considered and details are given here.

A specific ALARA investment is a 2-inch plate of iron or equivalent material that moves into place when a person enters the Target Room in order to shield out the gamma radiation from the activated beam stop. It is estimated to take 30 seconds to move such a shield into place. Based on one entry every 5 minutes to change a sample, approximately 20% more time (one minute every 5 minutes) is needed to move the shield into and out of the beam path before each experimental irradiation. Some of this time will overlap with the time it takes to enter and exit the target room if the shield's motion begins as a person enters or leaves. Integrated over a 1500-hour running period, the shield may idle the program significantly each year because of the delay involved in moving the shield. The cost of additional electric power to keep the beam line idle and ready for beam is significant. Approximately 0.5 MW are needed to maintain that portion of the beam line that would remain on during accesses to change samples in the Target Room. At this time (FY2001), the cost per MW-hr is \$60. For a 7% increase in idle time, one hundred hours per year, the cost is \$3000. A 7% increase is used as opposed to the full 20% increase since some time overlaps with User access and egress. In addition to this cost, the cost of the movable shield itself is approximately \$7,000. This includes the cost of labor for fabrication and installation (\$2000), materials (\$3000), and security hook-up (\$2000). It is noted that interlocks are needed to ensure the shield is out of the beam path during irradiations.

Additional factors such as impact on experiments and reduced area allotted for experiments are also considered. For example, frequent rapid entry may be needed for certain types of experiments or experimental runs. In this case, the shield would not be used. Quick entry, simple target mounting and quick exiting procedures would be the focus of ALARA efforts. On the other hand, for some experiments significant set-up time may be called for and a beam-stop shield would be beneficial. Finally, the area allotted for experiments is limited due the fixed size of the Target Room. The shield and mechanism to move the shield may need to be removed in order to accommodate a future experiment.

Based on the above, a cost-benefit analysis does not suggest a movable shield for the Booster beam stop is warranted. Total cost is about \$10,000 and total benefit is about \$5400 since dose from the gamma-shine is reduced, not eliminated. However, other factors, which are desire to minimize User exposures and cultivation of good will, dominate the eventual decision, even though these factors are not part of the cost-benefit analysis. Thus, a movable shield will be installed and it will be used whenever practicable.

The use of a person-rem period of one year is reasonable in this case. One can choose between short-term cost-benefit analysis and long-term cost-benefit analysis. In this case, power costs were annualized and future dose received by Users was not discounted to account for dose received during shield repairs or removal. The future costs of decommissioning were not included nor were the costs of future annual interlock testing

and repair. These types of costs are pertinent to long-term cost-benefit analysis. On the detriment side of the equation, there was an assumption in the dose calculation of 30 days of continuous irradiation with full beam on the dump. It was also assumed that Users worked only on the downstream side of the target, which pushed the short-term dose estimate upward. One could include future years' dose to Users and do a long-term cost benefit analysis, but one should consider the actual up and down running period that is likely to occur, and the actual positions of users. One would need to account for buildup and decay at night, on weekends and during downtimes. In addition, one needs compare this future detriment against all the long-term costs of the shield. The short-term approach was done in the spirit of DOE G 441.1-2, whereby the level of effort involved in documenting ALARA decisions should be commensurate with the potential dose savings to be realized.

### Identification Of The Applicable Radiological Design Criteria

From the SBMS Subject Area for Accelerator Safety, the applicable BNL design criteria, which have been met, are:

- Less than 25 mrem in one year to individuals in other BNL Departments or Divisions adjacent to the BAF.
- Less than 5 mrem in one year to a person located at the site boundary.
- Offsite drinking water concentration and on-site potable well water concentration less than 4 mrem to an individual in one year from BAF operations.
- Less than 1000 mrem in one year to a Collider-Accelerator Department staff member or User from operation and maintenance of BAF.
- Less than 10,000 pCi/L tritium concentration of in the BNL sanitary sewer effluent caused by liquid discharges from BAF averaged over a 30-day interval.
- Groundwater contamination from BAF soil activation is to be prevented.
- Less than 0.1 mrem in one year to a person at the site boundary from BAF airborne effluents.

It is noted that the C-A Department planned the BAF shielding with ALARA in mind, which is that during normal operations, the dose rate on accessible outside surfaces of the shield is planned to be less than 0.25 mrem/h in areas under access control.<sup>6</sup> Assuming 100% occupancy at the shield face, a 2000-hour per year residence time yields an acceptable ALARA design objective of 500 mrem. The 500 mrem per year ALARA design objective is one half the design objective stated in 10CFR835 § 835.1002 (b). Since there are many ways to control access and residence time by area designation, training, signage and work planning and since there is a decrease of dose rate with distance from the shield face, significantly higher shield face doses are often acceptable, but well within the ALARA design objective.

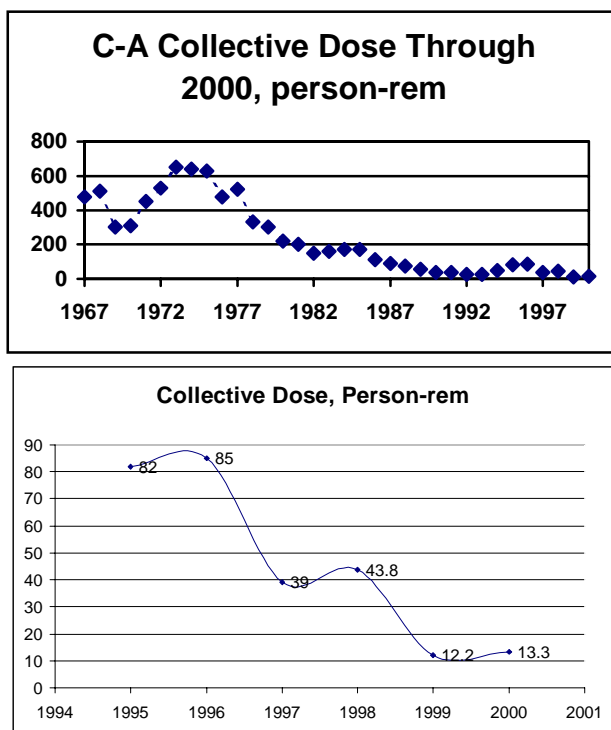
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<sup>6</sup> See the BAF SAD Chapter 4, Section 4.6.1.1.

### Review Of Previous Similar Jobs, Designs And Processes That Have Similar Hazards

Based on actual monthly doses for the 1999 and 2000 operating cycles for RHIC and NASA programs, approximately 250 person-mrem are accumulated per month of collider-accelerator operation and 1500 person-mrem per month of collider-accelerator maintenance.<sup>7</sup> Collider-accelerator operations were performed with high-energy heavy-ions similar to the proposed NASA program at BAF; however, dose from maintenance reflects high intensity proton operations as well. These values of collective dose are for Collider-Accelerator staff and Users who are radiation workers. Given that heavy ions from BAF program represent less than 0.01% of the total nucleons accelerated in the Booster in any given year, it is unlikely that BAF will affect C-A Department collective dose to any significant extent.

Collective-dose from operations and maintenance of the TVDG, Linac, Booster and AGS accelerators were factored into the monthly collective-dose estimates. It is noted that only the TVDG or Linac and the Booster are required for BAF heavy ion or proton operations. Overall, radiation exposure reduction is managed effectively at the complex; see the following figures. It is noted that physics programs, the number of radiation workers and the beam intensity have been increasing over the last four decades while the collective dose has been steadily decreasing.



The greatest amount of dose-reduction has come by way of Accelerator Improvement Projects. Funds from these projects were used by the C-A Department to improve the

<sup>7</sup> BNL Memorandum, C. Schaefer to D. Lowenstein, C-A FY 2001 Collective Dose Goal, October 12, 2000.

reliability of vacuum systems, beam injection systems and beam extraction systems. Additionally, the Experimental Support and Facilities Division designed radiation-hardened magnets that can operate properly after very high doses. This has resulted in fewer repairs, which in turn reduces the dose burden because staff is working less frequently on broken, activated equipment. Additionally, the Accelerator Division has improved beam monitoring systems and procedures that achieve better control of beams, which results in less activation of equipment.

### BAF Features To Reduce Dose And The Spread Of Radioactive Materials

- Soil is capped with a water-impermeable membrane to prevent soil activation from becoming a leachate that can reach groundwater.
- Multi-leg penetrations and labyrinths are used to minimize routine radiation levels.
- A re-entrant cavity and movable shield are used to minimize exposure to residual radiation in the Target Room from beam stop radioactivity.
- A sample translator or relay apparatus is used, when applicable, to minimize entrances to the Target Room.
- A sump and sump alarm are located in the beam line to capture cooling water should it leak.
- All drain piping in the facility is connected to the BNL Sanitary Sewage System.
- All cooling water systems have water make-up alarms.
- There are no outdoor tritiated water piping or cooling systems.
- An isolated closed cooling-water system was used to reduce the volume of tritiated water.
- The domestic water supply is equipped with back-flow preventers to isolate the Booster Applications Facility domestic water supply systems.
- Hoods and individual laboratory ventilation are used for radioactive tracer materials and hazardous materials in the Support Laboratories.
- Air and short-lived airborne radioactivity are re-circulated to allow for decay in the Booster Applications Facility beam line during operations.
- Air emissions from the Target Room are vented to the outside. Airflow direction is from the Support Laboratories into the Target Room and out the exhaust point.
- Dual, fail-safe interlocks are used on gate entrances.
- Interlocked access-key-trees are used to capture gate access keys.
- An iris reader or a similar bio-identification system is used to release an access key to a trained individual.
- Crash cords are mounted inside the target cave and beam line.
- Interlocking area radiation monitors with pre-set trip levels are located throughout the Booster Applications Facility.
- Audible and visual warnings are issued before re-enabling the beam line and target cave to receive beam.
- The beam line and Target Room are fully enclosed to prevent access during operations.
- Fencing is used to limit access to other radiological areas.
- Shielding is thick enough to prevent exposure to primary beam.

Post-Construction Review Of Effectiveness Of Engineering Features

The following post-construction reviews are required by C-A OPM procedures:

- Activated soil caps are examined for cracks, tree or shrub root penetration and standing water annually, before each running period.
- Fault studies aimed at proving the effectiveness of shielding and the optimum placement of fixed radiation monitors are conducted before routine operations.
- The access control system is tested before operations with beam and annually thereafter.
- Fencing and posting is examined by the liaison engineer and liaison physicist before initial operations with beam, and before each running period thereafter.
- Groundwater monitoring results are examined annually by C-AD management.
- Collective-dose is reviewed by the ALARA Committee annually.



## MEMORANDUM

Date: 01/17/01

To: R. Prigl, A. Rusek

From: A.J. Stevens

Subj.: Estimate of Induced Activity Near the BAF Beam Dump

This memorandum is intended to document a recent estimate of induced activity near the BAF beam dump. The estimate was made using the methodology described in Barbier.<sup>1</sup> Specifically, the induced activity at some point in space P due to an irradiated object subtending a solid angle  $d\Omega$  as viewed from P is given by:

$$Ac(P) = D \times \frac{d\Omega}{4\pi} \times \Phi \times B$$

where D is the "Danger Parameter" as constructed for various materials and at various energies by Barbier,  $\Phi$  is the activating flux, and B is a photon "build-up factor."<sup>2</sup>

Now Barbier does not explicitly consider the danger parameter for concrete or for irradiating ions. I have estimated danger parameters for concrete (given irradiating nucleons) by simply approximating concrete as 96% SiO<sub>2</sub> and 4% Al. The result of this estimate is shown in Figs. 1 and 2 for 50 MeV irradiation energy and 500 MeV respectively.

It should be noted that this is one aspect of radiological concern where the assumption that the hazard is proportional only to GeV-nucleons breaks down. In this case, the hazard is from photons created in the beam dump. The photons have a relatively short attenuation length, so photons created "deep" in the dump are simply irrelevant, only photons near the surface count. However, incident nucleons have a much longer interaction length than (say) incident Fe ions, so the approximation that 56 incident protons creates the same hazard as 1 Fe ion would simply be incorrect, even if the same number of photons would exist integrating over the dump.

I briefly describe here how the incident Fe (the typical ion) problem was approached. Two MCNPX calculations were done with a large (R=15 cm radius) beam incident on a simple block of concrete, 30 cm. long and 30 cm. radius. The first calculation was done with 300 MeV protons and the second with 1200 MeV (300 MeV per nucleon) alphas.<sup>3</sup> The number of nucleons > 20 MeV as a function of distance in the block is shown in the first two sets of points in Fig. 3. Note that, as expected, 4 times the number of nucleons from incident protons falls below the number of nucleons from incident alphas at short distances into the dump. The

triangles shown in the figure are the result of a very simple model, which is not described here, applied to the alpha points and normalized at  $Z = 2.0$  cm. The circles are the model results scaled to incident Fe nuclei (but still showing the number of nucleons per 4 incident nucleons). The number of created irradiating nucleons will be taken as the value at  $Z = 6$  cm.<sup>4</sup> using this scaling, or 1.8 per 4 nucleons at 300 MeV.

In addition to the produced nucleons, the incident beam is itself a (large) part of the irradiating flux. Now the total incident nucleons per year on the dump is limited at  $3 \times 10^{16}$  GeV-nucleons in 1500 hours. This is  $10^{17}$  300 MeV nucleons per 1500 hours or  $1.85 \times 10^{10}$  300 MeV nucleons per second. The beam flux is  $1/A_b$  per nucleon ( $A_b$  = beam area =  $707 \text{ cm}^2$  in this case) or  $1.414 \times 10^{-3}$  per  $\text{cm}^2$  per nucleon in comparison to the hadron flux which is  $(1.8/4) \div A_b$  or  $6.4 \times 10^{-4}$  per  $\text{cm}^2$  per nucleon.

With the point of evaluation at the end wall, immediately outside 3 ft recess, the  $d\Omega/4\pi$  becomes  $6.73 \times 10^{-3}$ . Multiplying by the  $1.85 \times 10^{10}$  and taking a build-up factor of 2.5 gives the following expression:

$$Ac = 3.1 \times 10^8 \times (1.414 \times 10^{-3} D(500) + 6.4 \times 10^{-4} D(50))$$

For 30 days irradiation the following table results:

Cooling Time (days)	Estimated Activity (mrem/hr)
.01	15.6
.1	13.8
1.0	4.5
5.0	.13
10.0	.10

Ed Lessard, using the estimated fluxes here, together with cross-sections from “Rudstam’s formula”<sup>5</sup> and the MicroShield code, obtains an almost identical result. **In both estimates, however, all isotopes with half lives less than 5 minutes have been ignored.** Although this is normally an acceptable approximation, the BAF users wish something close to “immediate” access, so the best estimate of the actual hazard will be greater than the  $\sim 16$  mrem/hr. estimate. Also, the beam rate taken is the limit of the annual *average*. If, for example, an order of magnitude higher hourly rate would exist for an exposure period of 1 day, the 15 minute(.01 day) estimate would be about 100 mrem.

According to C-A OPM 9.5.6, ALARA policy relating to cost/benefit analysis of dose reduction measures is that expenses less than \$11K per person-rem over the lifetime of the facility are appropriate. One possibility that should be discussed is a photon shield which would be moved to cover the re-entrant dump cavity during “beam-off” periods. Unfortunately, the relatively high energy of the activity<sup>4</sup> is somewhat difficult to shield. Two inches of steel or 1 inch of lead with a steel plate cover obtains a reduction factor of about 4.

### References/Footnotes

1. M. Barbier, "Induced Radioactivity," John Wiley & Sons, Inc. New York (1969.)
2. The build-up factor applies only to "thick" bodies which certainly describes the dump. See Fig. I.40 in Barbier.
3. MCNPX allows alphas as incidents, but not higher mass nuclei. There is also a problem with energies much above 300 MeV.
4. Ed Lessard points out that a substantial part of the dose comes from a 2.75 meV photon. The linear attenuation length for such a photon in concrete is about 12 cm.
5. Barbier, p. 98. The Rudstam cross-sections are a part of Barbier's Danger Parameters, so the two methods are not really independent.

Cc: E. Lessard

Danger Parameter, Concrete

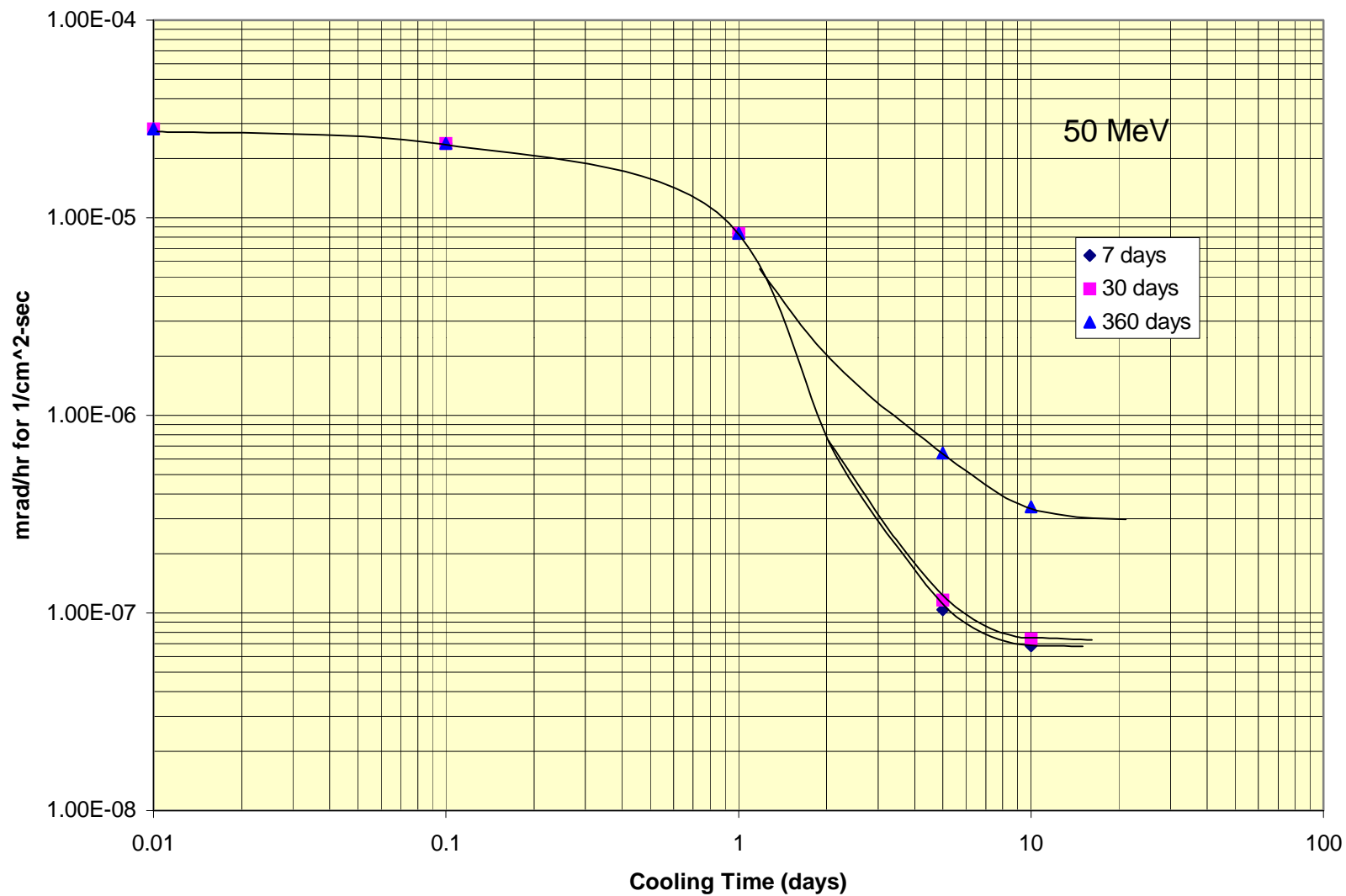


Fig. 1 Estimated Danger Parameter for Concrete for 50 MeV. The Textbox Shows Irradiation Times

Danger Parameter, Concrete

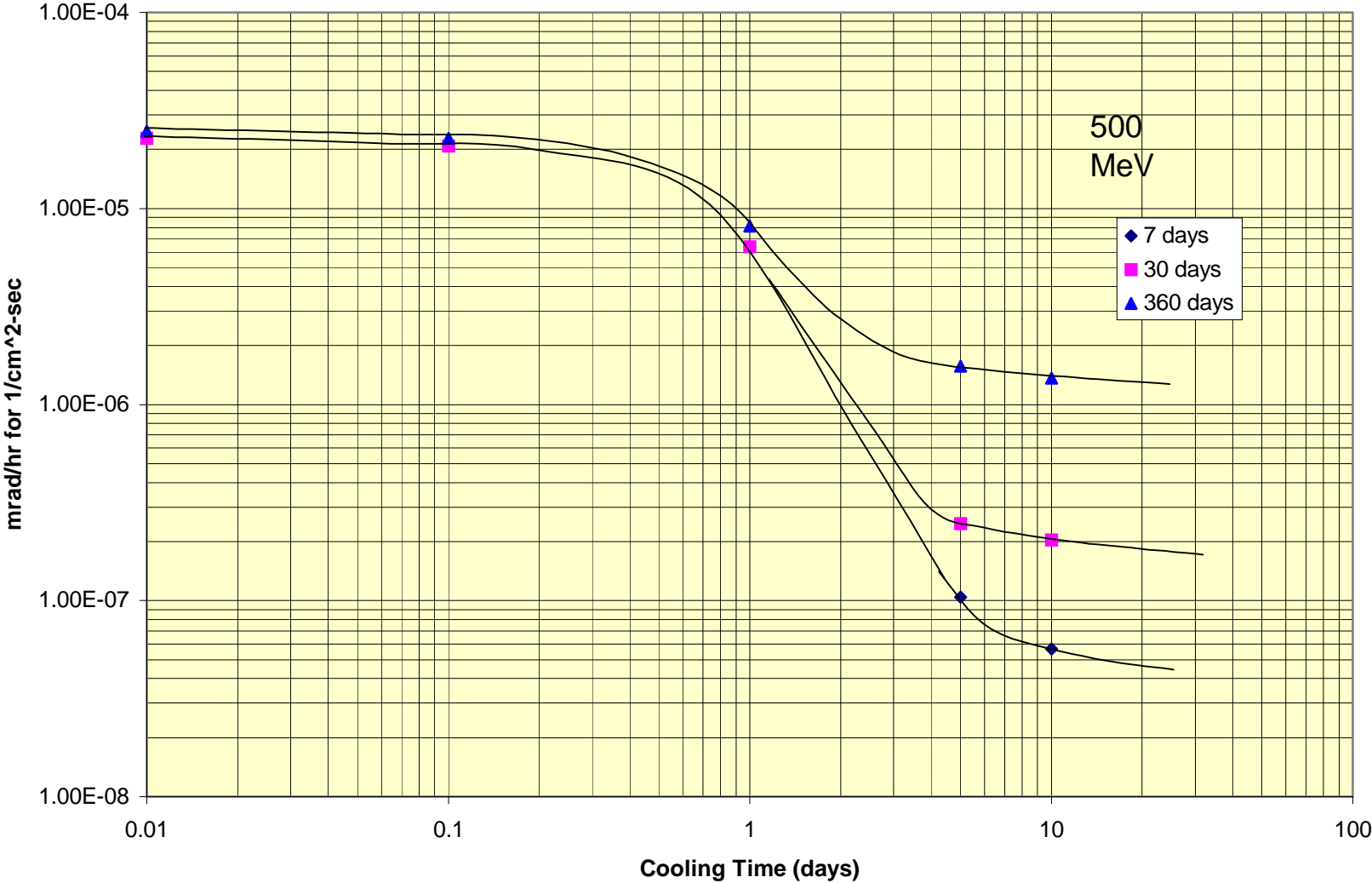


Fig. 2 Estimated Danger Parameter for Concrete for 500 MeV. The Textbox Shows Irradiation Times

### Total nucleons vs. Distance

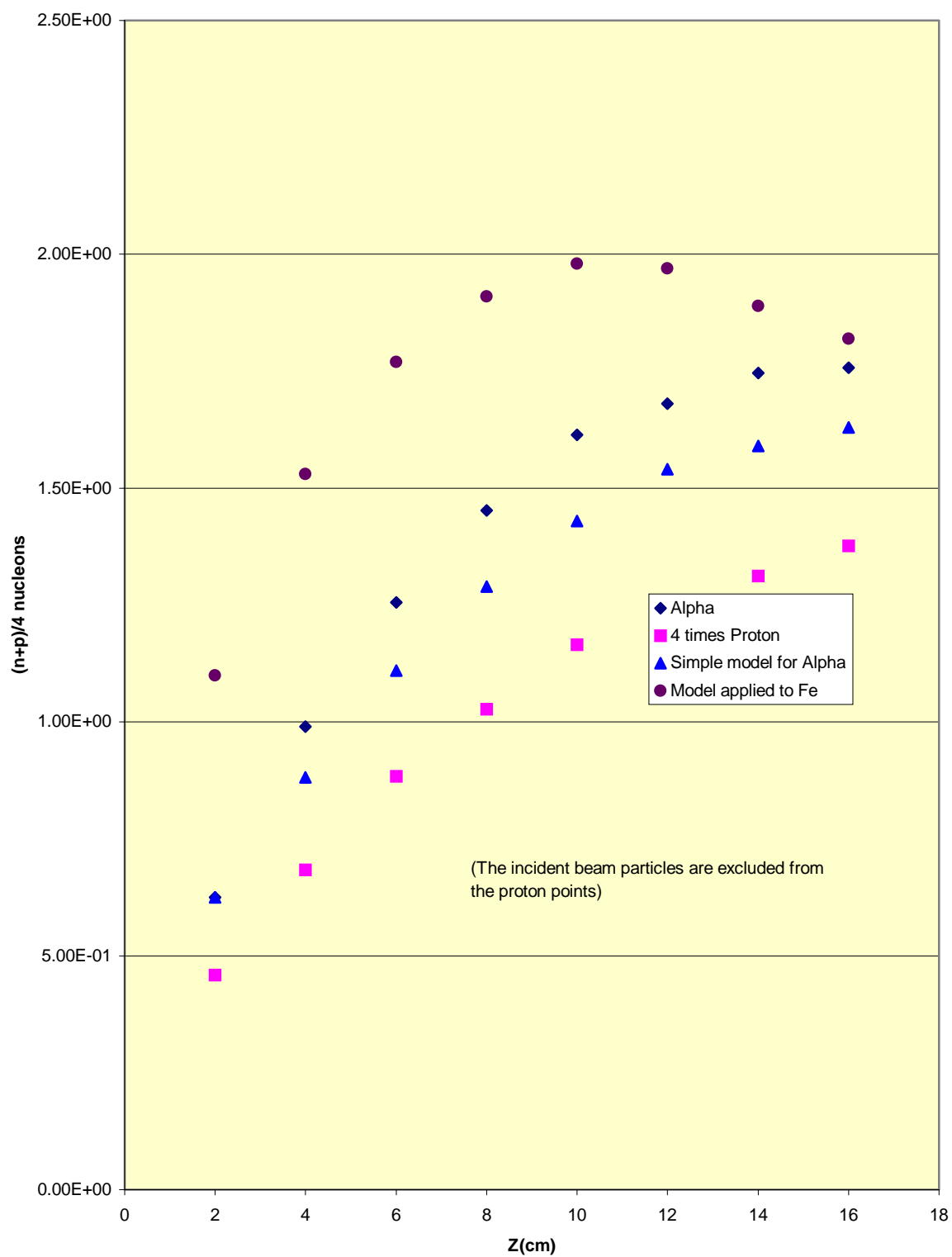


Fig. 3 Results from 300 MeV incidents on Concrete Block (see text)

**Fire Protection Assessment / Fire Hazard Analysis  
Building 956, 957, 959, Booster Application Facility  
Brookhaven National Laboratory**

Prepared by: J. W. Levesque  
J. Levesque, Fire Protection Engineer

Project Concurrence: A. McNerney  
A. McNerney, Project Manager

Date of Survey: May 7, 2001  
Date of Report: May 7, 2001

Conferred with: Andy McNerney, Project Manager  
Dave Phillips, BAF Liaison Engineer

**Purpose/Scope**

The purpose of this assessment is to comprehensively and qualitatively assess the risk from fire within the Booster Application Facility (BAF) Complex to ensure DOE fire safety objectives are met. DOE fire protection criteria are outlined in DOE Order 420.1<sup>1</sup>, Chapter 4. The fire protection assessment includes identifying the risks from fire and related hazards (direct flame impingement, hot gases, smoke migration, fire-fighting water damage, etc.). A Fire Hazard Analysis (FHA), required for the Safety Analysis Document for the BAF Complex, is incorporated into this assessment.

**Summary**

The planned use of the BAF Complex is described in the "Occupancy and Associated Fire Hazards", section below. These descriptions are based on field surveys, a review of the planned and completed installations, and discussions with BAF project staff. This assessment and FHA demonstrates the achievement of a reasonable and equivalent level of fire safety that meets DOE improved risk objectives.

**Recommendations:**

- 1) Propane gas cylinder storage should be located exterior to the building to minimize the risk to the occupants and experimental facilities.
- 2) The load management plan for the existing AGS emergency generators should be updated to ensure adequate electrical supplies are available for the BAF Complex's emergency load.
- 3) Backup of data collected as part of this program should be examined to ensure it is being adequately protected in accordance with DOE requirements.

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<sup>1</sup>US Department of Energy Order No. 420.1, Facility Safety, 11/16/95

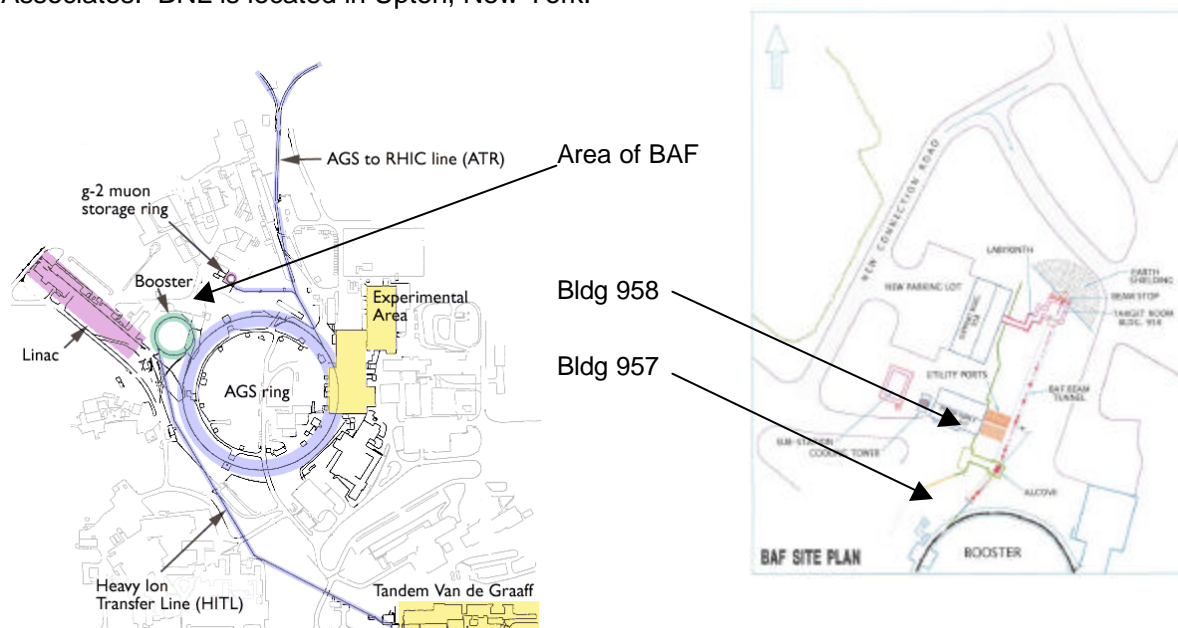
## Analysis

### 0. Scope

The assessment and analysis of the BAF Complex is divided into three fire areas; the Target Room and Tunnel (Bldg. 956), the Power Supply Building (Bldg. 957), and the BAF Support Building (Bldg. 958). This assessment and FHA does not include any portion of the Booster or other AGS facilities. Physical features provide isolation with respect to fire propagation between the fire areas and from the Booster and other AGS facilities. This assessment and FHA are based on information supplied by the BAF project and on a review of construction drawings and specifications (Plant engineering Job Number 8976).

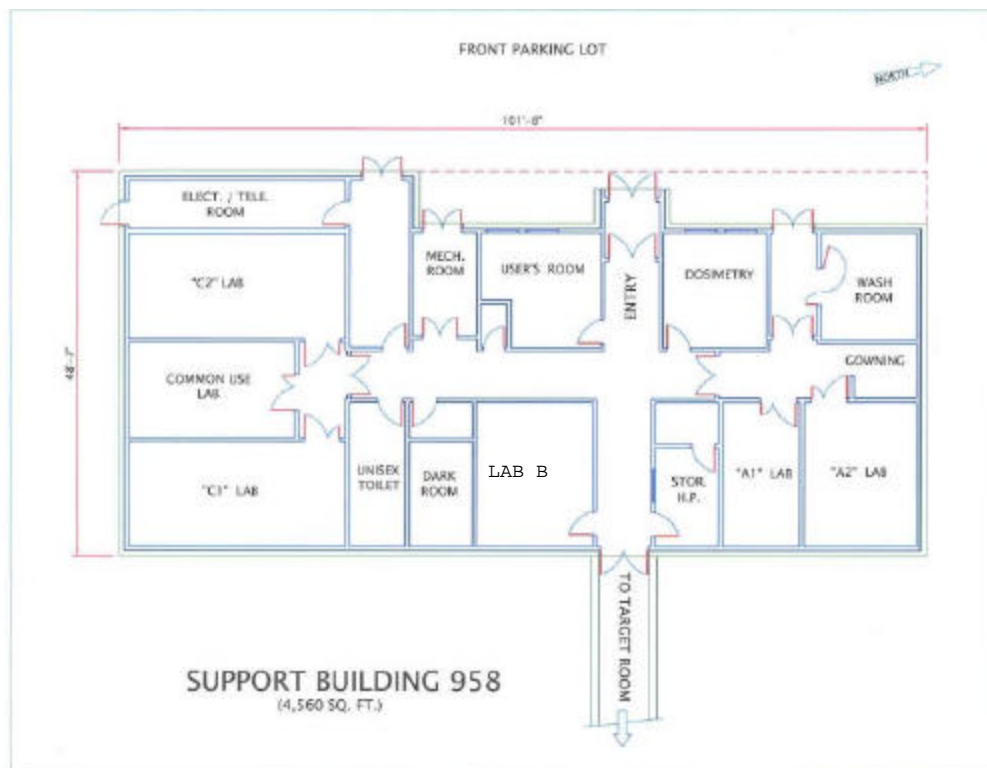
### 1. Construction

The BAF Complex is located in the northern region of Brookhaven National Laboratory (BNL). BNL is a 5,000 acre site owned by the Department of Energy and operated by Brookhaven Science Associates. BNL is located in Upton, New York.



### Building 958 (BAF Support Building)

Currently under construction, the BAF Support Building is a one story high pre-engineered structure, with a floor dimensions of 100 ft. by 40 ft (interior dimensions). The building walls are masonry for the first few feet and then constructed of insulated metal panels on steel frames for the remaining height. The roof is a sloped insulated metal roof with fiberglass insulation added beneath. The walls and roof assemblies are considered to be equivalent to non-combustible construction. The foundation is poured concrete. Interior walls are gypsum board on steel stud. A non-combustible suspended ceiling is being provided. There are no interior fire barriers.



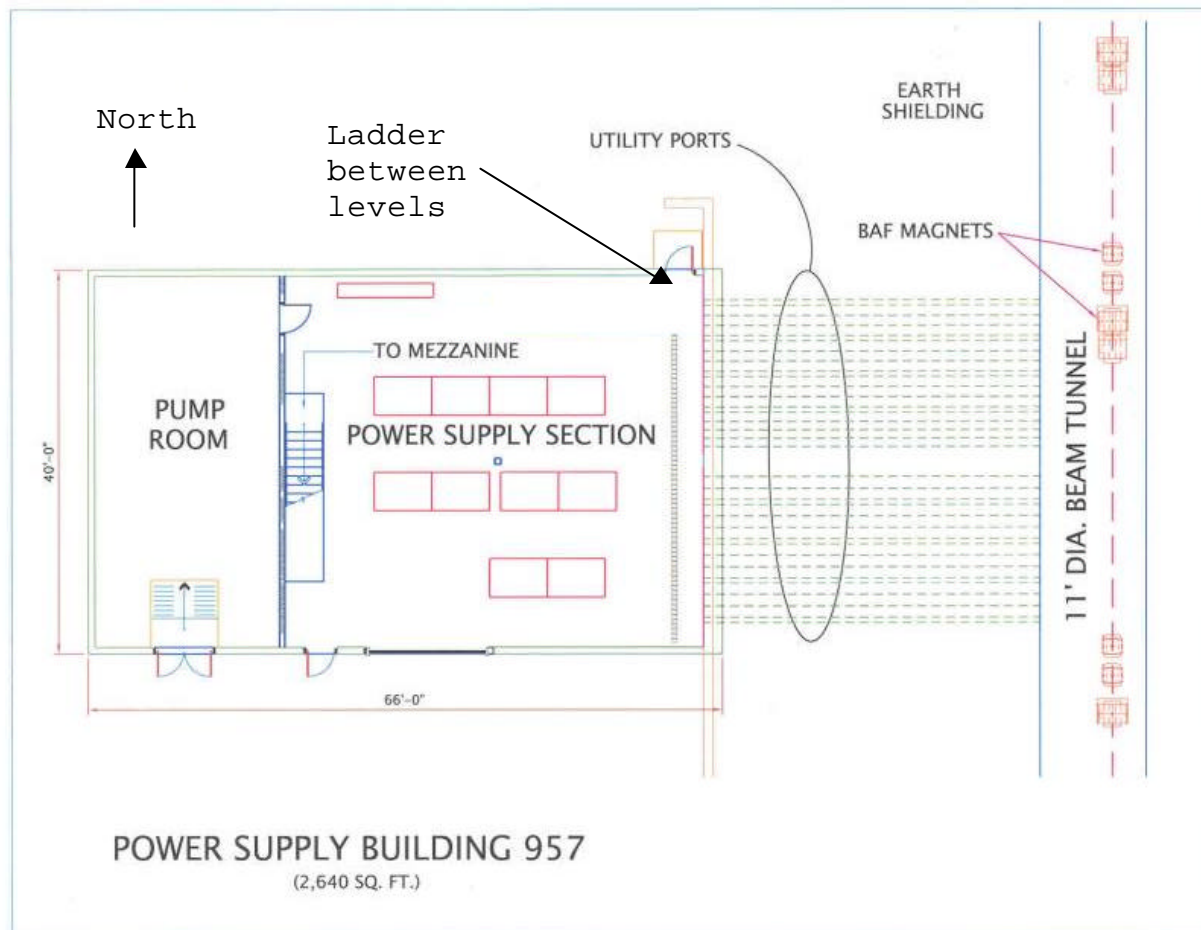
#### Building 956 (Target Room and Tunnel)

Currently under construction, the Target Room is a 20 ft. by 20 ft. by 10 ft. high (interior dimensions) poured concrete room. The flame spread rating of the finish is considered to meet ASTM E-84 Class A rating. The room is located underground and is connected to the BAF Support Building by a poured concrete labyrinth on the west side. The Target Room connects to the tunnel on the south side. The accelerator beam line enters through the tunnel opening. A radiation security gate and door separate the Target Room from the Tunnel. The structure is windowless and does not contain interior fire barriers.

The tunnel is constructed from a corrugated metal tube, 11 ft. in diameter. Concrete flooring will be provided. The flame spread rating of the finish is considered to meet ASTM E-84 Class A rating. The tunnel is located underneath approximately 15 ft. of earth (for radiation shielding). The structure is windowless and does not contain interior fire barriers.

#### Building 957 (Power Supply Building)

The Power Supply Building is currently under construction. The building is 65 ft. by 40 ft. (interior dimensions) with a concrete slab floor. The Power Supply Building is a two-story high building constructed of non-combustible pre-engineered insulated metal walls and roof. The second floor has been created by the installation of a metal mezzanine. A metal cooling tower is being installed to the west of the Power Supply Building.



An electrical substation is located to the west of Bldg. 957. The 1500 kVa and 2000 kVa electrical transformers and switch gear are arranged to meet the recommendations in Factory Mutual Loss Prevention Data Sheet 5-4 for fire protection. The transformers do not present an exposure hazard to the facility or each other.

### 1.1 Fire Barriers

There are no requirements for fire barriers for hazard separations. Facility values and loss potentials are well below the DOE \$50 million threshold for fire barriers.

The BAF is isolated from the AGS Booster by several feet of earth shielding. A metal vacuum beamline penetrates the shielding between the BAF and the AGS Booster. The area lacks combustibles and will not convey fire from the Booster to the BAF. While this arrangement is not a rated firewall assemble, it serves as physical isolation of the Booster (Bldg. 942) and the BAF complex.

### 1.2 Windstorm Damage Potential

The insulated metal deck roofs of Bldg. 957 and Bldg. 958 are designed to withstand local windstorms as per New York State Building Code. There are no windstorm concerns with the underground Target Room and Tunnel.

## 2. Occupancy and Associate Fire Hazards

The BAF project is intended to simulate radiation fields encountered in space that may cause deleterious effects in humans during prolonged space missions. The BAF Support Building will be used for cell and animal target preparation and assessment. The cell preparation laboratories will store and prepare cell cultures. Animal study rooms will house and prepare animals. Minimal flammable liquids will be used (1 quart quantities and less) in these laboratories. Toxic materials and infectious organisms will not be used. Due to the potential for biohazards being present in the building, the area will be considered a Biosafety Level II facility by National Institute of Health Standards (see below for more details).

### 2.1 Critical Process Equipment

The following table list the systems that will be present in the complex, their values (including development costs) and their expected replacement values (without salvage).

Location	System	Total Cost(\$k)	Estimated Replacement Cost(\$k) (material & labor, less engineering)
<b>BAF Tunnel</b>			
	Magnets	\$470	\$155
	Instrumentation	\$750	\$365
	Vacuum	\$645	\$305
	Target Room-Dosimetry	\$1,000	\$250
<b>Experimental Support Bldg.</b>			
	Dosimetry Room - Dosimetry	\$1,400	\$600
	Laboratories – Lab Equipment	\$278	\$206
<b>Power Supply Bldg.</b>			
	Power Supplies	\$850	\$550
	Instrumentation	\$750	\$200
	Vacuum	\$200	\$100
	Pump Room -Pumps & Heat Exchanger	\$420	\$100

### 2.2 Special Occupancies

Special occupancies include electronic data processing and vital/important records. The special occupancies of BAF are expanded upon in sections 2.2.1 and 2.2.2, below.

#### 2.2.1 Electronic Data Processing

The Dosimetry Room, located in the Support Building, contains high valued electronics for measuring delivered dose to the target organisms. The Physics Lab (Lab B), also located in the Service Building, contains high valued electronics for data collection. Bldg. 958 is fully sprinklered and the Dosimetry Room and Physics Lab are provided with early warning smoke detectors. With early warning smoke detectors and the presence of facility sprinkler protection, the electronic data

processing areas are suitable for equipment values over \$25 million dollars. Total values of each area are under \$1 million dollars.

### 2.2.2 Vital and Important Records Storage

Vital records are those records which are essential to the mission of an important program and which, if lost, could not be reproduced or obtained elsewhere. Important records are those records possessing a high value to the mission of an important program but which, if lost, could be reproduced or reconstructed with difficulty or extra expense.

Based on the above definition, the data collected from the experiments are considered vital records. Backup of data collected as part of this program should be examined to ensure it is being adequately protected in accordance with DOE requirements (recommendation #3).

### 2.3 Unique Fire Hazards

Unique fire hazards include; trailers, cooling towers, flammable liquid and gas storage, cable trays, housekeeping in vital areas, and highly combustible building materials. The unique fire hazards at the BAF Complex are expanded upon in sections 2.3.1 through 2.3.6, below.

#### 2.3.1 Trailers

No trailers are planned. However, if trailers are needed at a later date, their installation and use will follow BNL standards. BNL standards require compliance with the DOE Standard on Portable Structures.

#### 2.3.2 Cooling Towers

The experimental system has a water-based heat removal system. One cooling tower is located to the west of Bldg. 957. The unit is metal, prefabricated, and serves the BAF magnet cooling water system, and the power supply/buss cooling system. A fire in the cooling tower will not cause damage to the main buildings due to spatial separation and the limited amount of combustibles in the tower.

#### 2.3.3 Flammable Liquid & Gas Storage

The use of flammable liquids will be minimal. The anticipated use of solvents will be less than 1 quart in each laboratory space. Use of flammable liquids will follow BNL ES&H Standards (found at <https://sbms.bnl.gov/ld/ld08/ld08d481.pdf>).

The only use of a flammable gas will be for Bunsen burners in the lab spaces. Propane gas will be distributed through a fixed piping system. Current plans show the gas distribution supply located in the electrical mechanical room of the Support Building (recommendation #1). The use of all flammable gases will follow BNL Standards found at <https://sbms.bnl.gov/ld/ld08/ld08d491.pdf>.

#### 2.3.4 Cable Trays

High voltage, low voltage, control, and signaling cables are to be segregated in accordance with NEC requirements throughout the BAF Complex. The cabling is located in conduits, raceways and cable trays. In most instances, the cables provided in the cable trays meet the flammability test criteria in IEEE 383, VW-1, and/or NEC rated wire for cable trays. These less flammable cables

decrease the overall fuel loading and loss potential in the tunnel, making the need for sprinkler protection in the tunnel unnecessary.

#### 2.3.5 Housekeeping in Vital Areas

For this high value facility, good housekeeping and control of combustibles will be essential. The Collider-Accelerator Department self-inspection program will be extended to this complex.

#### 2.3.6 Highly Combustible Building Materials

No significant amounts of exposed polystyrene insulation or other highly combustible building materials are used in the construction or operations at the BAF Complex.

### 3. Fire Protection/Suppression Features

#### 3.1 Site Water System

BNL has a combination domestic and fire protection water supply system. The system is supplied by several deep wells and is stabilized by two elevated water storage tanks (one 1 million gallon and 350,000gallon capacity). The wells have electric primary drivers and a limited number have backup internal combustion drivers. The system can sustain three days of domestic supply and a maximum fire demand (4,000 gpm for 4 hours) for BNL with two of the system's largest pumps out and one storage tank unavailable. The piping distribution network is well gridded. The distribution system in the area of the BAF Complex has a static supply pressure of 68 psi. The piping system can supply 958 gpm at 51 psi residual pressure. This supply is adequate for the automatic sprinkler system in the Support Building

Fire hydrants are provided within 300 ft. of each facility. Frost proof hydrants are needed since the frost line extends to 4 feet below the surface in the winter. BNL and the local Suffolk County Fire Departments use National Standard Thread couplings.

BNL's Plant Engineering Division maintains the water supply system. BNL's Fire/Rescue Group conducts valve inspections on the distribution system to ensure reliability of firefighting water supplies.

#### 3.2 BNL Fire/Rescue Group

The BNL Fire/Rescue Group is a full time, paid department. Minimum staffing is five firefighters and one officer per shift. The firefighters are trained to meet Firefighter Level III by International Fire Service Training Association standard, National Fire Protection Association (NFPA) Fire Fighter Level II standard, and (NFPA) Hazardous Material Technician Level and they are Suffolk County Certified Confined Space Rescuers.

The BNL Fire/Rescue Group also provides emergency medical services to an on-site population of 3200 people. A minimum of two members per shift hold New York State "Emergency Medical Technician - D" certifications ("D" is for defibrillation). Normally all five firefighters have EMT status. The Group operates a New York State Certified Basic Life Support ambulance (a 1988 Wheeled Coach Type I on a Type III Chassis). Medivac services are available to BNL via the Suffolk County Police Department (a training session).

Additionally the Fire/Rescue Group has two 1500 gpm. "Class A" Pumpers, one Rescue Vehicle for initial hazardous material incident response and heavy rescue operation, one Command Post Vehicle, one 5 ton military chassis converted to a Long Island Style Brush Truck.

The single Fire Station is located on the west side of the BNL Site. Response time to the most remote section of the BNL Site is less than eight minutes. Response time to the BAF Complex is estimated at 5 minutes.

BNL participates in the Suffolk County Mutual Aid Agreement. This allows the resources from over 130 departments to assist BNL. BNL is also a member of the Town of Brookhaven Foam Bank and Town of Brookhaven Hazardous Material Mutual Aid Agreement.

### 3.3 Site Fire Alarm System

Brookhaven National Laboratory provides central fire alarm station coverage by an Underwriter Laboratory listed multiplexed Site Fire Alarm System. The system is a Wormald System 1000, installed in 1987 (Wormald is now know as Grinnell Fire System). The system complies with the requirements of NFPA 72 for a Style 7D System.

The system uses the existing site telephone cable plant. RS232 signals are sent via full duplex line drivers. Each fire alarm panel has two channels connected to the Central Station. The panels are divided into 7 communication "loops." The system can monitor more than 20,000 points. It is currently monitoring 3,800. Response time from alarm at the panel to alarm indication at the Central Station is less than 10 seconds, which is well within the 90 seconds allowed by NFPA 72.

The main console is at the Firehouse, Bldg. 599. This station monitors all fire alarm signals, trouble and communication status alarms. A satellite station is provided at Safeguards and Security, Bldg. 50, and receives only the fire alarm signals. If the Firehouse does not acknowledge an alarm within 90 seconds, the satellite station at Bldg. 50 will receive an audible indication to handle the alarm. A second satellite station is provided at AGS Main Control Room, Bldg. 911, and receives only the fire alarm signals from the RHIC/AGS accelerator buildings. A team of operators and Health Physics Support personnel respond during accelerator operating times.

### 3.4 Fire Extinguishers

Fire extinguishers are being installed throughout the facilities in accordance with NFPA 10.

### 3.5 Target Room and Tunnel (Bldg. 956)

#### 3.5.1 Fire Department Standpipe

The Tunnel is provided with one fire department hose connection adjacent to the labyrinth entrance from the Target Building. With the tunnel having two entrances (one at the Target Building, one at the Power Supply Building) and only being 250 feet long, additional coverage is not necessary.

#### 3.5.2 Fire Detection and Suppression

The Target Room and Tunnel are provided with an automatic fire detection. Since there is limited combustible loading and the maximum possible fire loss potential of less than \$1 million dollars, automatic fire suppression is not warranted.

### 3.6 Power Supply Building (Bldg. 957) Fire Detection and Suppression

The Power Supply Building is provided with automatic fire detection. Smoke detection is provided in power supply areas. Areas with mechanical equipment are provided with heat detection. The facility is not provided with an automatic fire suppression system. The limited combustible loading and maximum possible fire loss potential of less than \$1 million dollars do not warrant a dedicated fire protection system for this building.

### 3.6 Support Building (Bldg. 958) Fire Detection and Suppression

The Support Building is provided with an automatic fire suppression system throughout the facility and early warning smoke detection system in areas containing high valued electronic equipment. The sprinkler system in the Support Building is designed to provide 0.15 gpm per square foot sprinkler density over 2500 sq. ft. of the most hydraulically remote area of the building while supplying 250 gpm for fire hose streams. The system requires 926 gpm at 43 psi.

### 4.1 Fire Protection of Vital Programs

The operations associated with this facility are not considered to be a DOE vital program. Therefore, no special fire protection precautions, beyond those that are generically described above, are required for this facility.

### 4.2 Fire Protection of High Value Property

The majority of the dollar value is concentrated in the Power Supply Building, the Target Room, and the Dosimetry Room. These areas are valued below \$25 Million and loss potentials are acceptable for these areas.

### 5.3 Protection of Essential Safety Class Systems

There are no essential safety class systems associated with this non-nuclear facility.

## 6. Fire Loss Potentials

Fire loss potentials are classified into two major categories; the maximum possible fire loss and the recovery potential. The loss potentials for the BAF Complex are expanded upon in sections 6.1 and 6.2, below.

### 6.1 Maximum Possible Fire Loss (MPFL)

The Maximum Possible Fire Loss (MPFL) for the BAF Complex is estimated separately for each of the three primary fire areas. The MPFL for the Tunnel and Target Building (Bldg. 956) is estimated to be less than \$250k (replacement costs). The MPFL for the Power Supply Building (Bldg. 957) is estimated to be less than \$750K (replacement costs). The MPFL for the Service Building (Bldg. 958) is conservatively estimated to be less than \$900k (replacement costs). Bldg. 958 is provided with automatic sprinkler protection as required by DOE for areas with an MPFL in excess of \$1 million.

### 6.2 Recovery Potential

## 7. Security Considerations Related to Fire Protection

The facility will have security measures to restrict access, including card readers and an iris scanner. Provisions will be made for Fire/Rescue access via card reader programming, provision of master key, or installation of interlocked crash doors. Radiation security barriers comply with the Life Safety Code for egress. Ingress will include interlocked crash panels in the doors to allow emergency entry.

### 7.1 Exposure Fire Potential

The BAF Complex is located in the northern part of BNL and borders the Pine Barrens wildlands. Established roadways provided engineered features that help protect the facility from a potential wildland fire. Pine trees and shrubs do not pose a potential exposure to the insulated metal structures. The roof systems will not ignite from burning brand produced in a brush fire.

The electrical substation to the west of Bldg. 957 does not pose a fire exposure to the complex, as previously described.

The cooling tower does not pose a fire exposure to the complex, as previously described.

No other facilities pose a fire exposure to the BAF Complex.

## 8. Environmental Impact due to a Fire (Including Water Runoff)

Toxic, biological, and radiation incidents resulting from a fire, including water runoff, are analyzed in sections 8.1 through 8.3, below.

### 8.1 Toxic Incident

There are no known materials in the BAF complex that, if involved in a fire, would result in a significant quantity of toxic material being created and released.

### 8.2 Biological Incident

While biological matter will be present in the laboratory spaces, the hazard is low. There are no aggressive organisms. The operations are being designed to meet the National Institute of Health Biosafety Level II since some biohazards may be present (typical hepatitis/HIV concerns). Other than pre-fire planning information, there are no fire issues related to blood borne pathogens.

### 8.3 Radiation Incident

By the nature of the operations of the accelerator, various pieces of equipment can become activated. This activation is not expected to pose a significant environmental impact in the event of a fire since the material will not be easily disbursed. Animals and cells that are part of the BAF experiments will not receive doses that will induce activation near levels of concern.

For calibration of instruments, several small sealed calibration sources will be present. These sources do not have the curie content or the physical state to be disbursed and contaminate large areas.

No other radioactive materials are used or stored in the BAF Complex.

## 9. Pre-fire and Emergency Planning

The BNL Fire Department maintains an adequate pre-fire plan book for this facility (<http://home.bnl.gov/emergencyservices/runcards/>).

A Local Emergency Plan is maintained for the BAF Complex. It includes CA Main Control Room actions to take with various alarms.

### 9.1 Fire Apparatus Accessibility

Fire apparatus accessibility is adequate for the main facility. Current parking lot configurations allow access by apparatus in the event of an emergency.

## 10. Life Safety Considerations

Major life safety considerations for this industrial facility include the following components; means of egress components and capacity, number and arrangement of the means of egress, travel distances to exits, discharge from the exits, and emergency lighting and marking of the means of egress.

The likelihood of a fast spreading fire is remote, given the nature of combustibles within the BAF facilities. Hence the facility is considered to be an ordinary hazard special purpose industrial

**FHA, BAF Complex, Bldg. 956, 957, 958**  
**Page 12**

occupancy. Emergency power is provided to the lighting throughout the facility. The emergency power source is an existing emergency generator at the AGS. The additional load should be included in the load management plan for the AGS generators to ensure adequacy of supplies (see Recommendation #2).

The anticipated occupancy load is less than 15 people in the Target Room and Tunnel. Two means of egress are provided. Both are conventional exits with radiation security gates that are crashable. The dead end created by the Tunnel at the connection to the AGS Booster Facility is within limits for an unsprinklered industrial occupancy.

Smoke removal ventilation is provided in the Tunnel. One 17,000 cfm exhaust fan is located at the tunnel's mid point. Two make-up airshafts are supplied by the exit points. Activation will be by manual stations at the fire alarm control panel and the labyrinth entrance to the tunnel. While smoke removal is not required by code, it is essential for fighting a fire in a windowless, underground facility.

Bldg. 958 (Support Building) is considered an industrial space with a typical occupancy under 25 people. Two remote exits are provided from the common corridor. The facility complies with the requirements of the Life Safety Code for an ordinary hazard occupancy without a significant use of flammable liquids. Laboratory spaces using significant quantities of flammable liquids would require a second means of egress from the space as opposed to the current single exit paths to the corridors. Flammable liquid usage will be controlled and monitored by the FUA and the departmental inspection program.

Bldg. 957 (Power Supply Building) is considered a special purpose industrial space with a typical occupancy load of under 10 people. The occupancy load of the mezzanine area is not expected to exceed three persons. The second floor mezzanine uses a ladder as a secondary means of egress to the ground floor as allowed by the Life Safety Code for boiler rooms and similar spaces subject to occupancy not to exceed three persons who are capable of using the ladder. The means of egress for Building 957 comply with the requirements of the Life Safety Code.

## BAF SAD Appendix 9

### BAF Qualitative Risk Assessment Screening

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## BAF SAD Appendix 9

Table A9-1  
Qualitative Risk Assessment for BAF - Vacuum

FACILITY NAME: BAF  
SYSTEM: Vacuum Beam Line  
SUB-SYSTEM: Vacuum System, Beam Window  
HAZARD: Vacuum

Event	Structural failure of vacuum boundary
Possible Consequences, Hazards	Implosion of any vacuum component could pose a potential health risk from flying objects.
Potential Initiators	Failure caused by worker mistake or inadvertent striking contact with vacuum boundary.

### Risk Assessment Prior to Mitigation

Note: Refer to Table 4.2.1 for an explanation of consequence, frequency and risk levels. "Low" and "Extremely Low" risk levels are considered acceptable.

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input checked="" type="radio"/> Low	<input type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input checked="" type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input checked="" type="radio"/> Low Risk	<input type="radio"/> Extremely Low

Hazard Mitigation	<ol style="list-style-type: none"> <li>1. Beam line vacuum components designed to meet C-A/industry standards.</li> <li>2. Vacuum and pressure systems reviewed by the C-A Chief Mechanical Engineer or his designate.</li> <li>3. Vacuum components, except for windows, are constructed of heavy-walled material, per ASME Boiler and Pressure Vessel Code, Section VIII to minimize the threat of implosion when evacuated.</li> <li>4. Training of Users and Staff.</li> </ol>
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### Risk Assessment Following Mitigation

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input checked="" type="radio"/> Low	<input type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input type="radio"/> Anticipated Medium	<input checked="" type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input type="radio"/> Low Risk	<input checked="" type="radio"/> Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.  
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

## BAF SAD Appendix 9

Table A9-2  
Qualitative Risk Assessment for BAF – External Events

FACILITY NAME: BAF

SYSTEM: Entire Facility

SUB-SYSTEM: N/A

HAZARD: External Event (Earthquake, Tornado, Hurricane, Flood, Aircraft Impact, Forest Fire)

Event	External event impacts BAF
Possible Consequences, Hazards	Equipment/building damage or programmatic impact.
Potential Initiators	Severe weather, flooding, forest fire, aircraft impact

### Risk Assessment Prior to Mitigation

Note: Refer to Table 4.2.1 for an explanation of consequence, frequency and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	<input checked="" type="radio"/> High	<input type="radio"/> Medium	<input type="radio"/> Low	<input type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input checked="" type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input type="radio"/> Low Risk	<input checked="" type="radio"/> Extremely Low

Hazard Mitigation	<ol style="list-style-type: none"> <li>1. Building designed to Uniform Building Code.</li> <li>2. Relatively small radioactive inventory cannot cause offsite health effects.</li> <li>3. BNL Fire Department can respond quickly to forest fire. BNL has firebreaks.</li> <li>4. No active systems needed to protect personnel from adverse health effects after accelerator off.</li> <li>5. Severe weather and flooding potential is extremely low. Warning of these impending hazards will allow for accelerator shutdown and for personnel safety.</li> <li>6. BNL Wildfire Prevention Program.</li> </ol>
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### Risk Assessment Following Mitigation

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input checked="" type="radio"/> Low	<input type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input checked="" type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input type="radio"/> Low Risk	<input checked="" type="radio"/> Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.

Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

## BAF SAD Appendix 9

Table A9-3  
Qualitative Risk Assessment for BAF – Electric Shock

FACILITY NAME: BAF  
SYSTEM: Facility  
SUB-SYSTEM: Magnets, Power Supplies, Instrumentation  
HAZARD: Electric Shock From Exposed Conductors

Event	Worker contacts energized conductor
Possible Consequences, Hazards	Shock, impact injury, burns
Potential Initiators	Worker falls, fails to control position of limbs or tools, equipment failure, improper work controls

### Risk Assessment Prior to Mitigation

Note: Refer to Table 4.2.1 for an explanation of consequence, frequency and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	<input checked="" type="checkbox"/> High	<input type="checkbox"/> Medium	<input type="checkbox"/> Low	<input type="checkbox"/> Extremely Low
Frequency	<input checked="" type="checkbox"/> Anticipated High	<input type="checkbox"/> Anticipated Medium	<input type="checkbox"/> Unlikely	<input type="checkbox"/> Extremely Unlikely
Risk Category	<input checked="" type="checkbox"/> High Risk	<input type="checkbox"/> Medium	<input type="checkbox"/> Low Risk	<input type="checkbox"/> Extremely Low

Hazard Mitigation	<ol style="list-style-type: none"> <li>1. Exposed conductors and terminals are covered for protection of personnel as per BNL Electrical Safety requirements.</li> <li>2. Training for workers/ experimenters.</li> <li>3. Use of work planning, LOTO and Working Hot Permits.</li> <li>4. Magnets de-energized when routine access allowed into tunnel.</li> <li>5. Review is performed for electrical safety on all non-commercial ‘in-house’ built equipment. Review is by the Chief Electrical Engineer or his designate.</li> </ol>
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### Risk Assessment Following Mitigation

Consequence	<input type="checkbox"/> High	<input type="checkbox"/> Medium	<input type="checkbox"/> Low	<input checked="" type="checkbox"/> Extremely Low
Frequency	<input type="checkbox"/> Anticipated High	<input type="checkbox"/> Anticipated Medium	<input checked="" type="checkbox"/> Unlikely	<input type="checkbox"/> Extremely Unlikely
Risk Category	<input type="checkbox"/> High Risk	<input type="checkbox"/> Medium	<input type="checkbox"/> Low Risk	<input checked="" type="checkbox"/> Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.

Is the hazard mitigation system needed for hazard control? Y/N Yes If Yes, need ASE requirement.

## BAF SAD Appendix 9

Table A9-4  
Qualitative Risk Assessment for BAF - Radiation

Facility Name: BAF

System: Areas Outside Beam Enclosures

Sub-System: BAF Beam Tunnel, Target Room, Entrances To Tunnel And Target Room

Hazard: Prompt Beam Radiation Outside Beam Enclosures

Event	Credible beam control fault
Possible Consequences, Hazards	Concrete and earth berm shielding, fenced areas, chicane design
Potential Initiators	Failure of magnet or magnet power supply, inefficient beam tuning

### Risk Assessment Prior to Mitigation

Note: Refer to Table 4.2.1 for an explanation of consequence, frequency, and risk levels. "Low" and "Extremely Low" risk levels are considered acceptable.

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input type="radio"/> Low	<input checked="" type="radio"/> Extremely Low
Frequency	<input checked="" type="radio"/> Anticipated High	<input type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input checked="" type="radio"/> Low Risk	<input type="radio"/> Extremely Low

Hazard Mitigation	<ol style="list-style-type: none"> <li>1. Beam information display and operating procedures. Beam tuned at low intensity.</li> <li>2. Operator/ Physicist training.</li> <li>3. Review of radiation safety by C-A RSC.</li> <li>4. Radiological area postings, fenced gates interlocked with beam.</li> <li>5. Chipmunk-interlocked beam cutoff on abnormal radiation levels.</li> <li>6. Sweep procedures prior to beam initiation.</li> <li>6. Periodic inspection of earthen berm to verify integrity.</li> </ol>
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### Risk Assessment Following Mitigation

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input type="radio"/> Low	<input checked="" type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input type="radio"/> Anticipated Medium	<input checked="" type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input type="radio"/> Low Risk	<input checked="" type="radio"/> Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.

Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

## BAF SAD Appendix 9

Table A9-5  
Qualitative Risk Assessment for BAF – Radiation

FACILITY NAME: BAF  
SYSTEM: Beam Enclosures  
SUB-SYSTEM: BAF Beam Line Tunnel, Target Room  
HAZARD: Prompt Beam Radiation Inside Beam Enclosures

Event	Person inside enclosure during beam operation.
Possible Consequences, Hazards	Personal injury or death due to external prompt radiation associated with beam.
Potential Initiators	Person inadvertently enters enclosure; person fails to leave before beam initiated.

### Risk Assessment Prior to Mitigation

Note: Refer to Table 4.2.1 for an explanation of consequence, frequency and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	<input checked="" type="radio"/> High	<input type="radio"/> Medium	<input type="radio"/> Low	<input type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input checked="" type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input checked="" type="radio"/> Medium	<input type="radio"/> Low Risk	<input type="radio"/> Extremely Low

Hazard Mitigation	<ol style="list-style-type: none"> <li>1. Operating procedures.</li> <li>2. Worker/experimenter training.</li> <li>3. Review of radiation safety by C-A RSC.</li> <li>4. Tunnel/target room sweep procedures.</li> <li>5. ACS door locks and other access controls.</li> <li>6. Audible/visual alarms initiated by ACS inside beam line tunnel and target room before beam initiation, allowing sufficient time for un-swept individuals to pull beam crash chord or exit enclosure to stop beam initiation.</li> <li>7. ACS automatic interlock to stop beam given access violation.</li> <li>8. ACS controls critical devices to automatically confine beam to Booster section, thus keeping beam out of downstream section with personnel inside.</li> </ol>
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### Risk Assessment Following Mitigation

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input checked="" type="radio"/> Low	<input type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input checked="" type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input type="radio"/> Low Risk	<input checked="" type="radio"/> Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.  
Is the hazard mitigation system needed for hazard control? Y/N Yes If Yes, need ASE requirement.

## BAF SAD Appendix 9

Table A9-6  
Qualitative Risk Assessment for BAF – Radiation

FACILITY NAME: BAF

SYSTEM: Beam Dump, Other Activated Components

SUB-SYSTEM: N/A

HAZARD: External Radiation From Activated Beam Dump, Activated Magnets And Other Components

Event	Worker/experimenter inside target room or tunnel during beam off periods
Possible Consequences, Hazards	Excessive external dose
Potential Initiators	Improper work planning, procedure violation

### Risk Assessment Prior to Mitigation

Note: Refer to Table 4.2.1 for an explanation of consequence, frequency and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input type="radio"/> Low	<input checked="" type="radio"/> Extremely Low
Frequency	<input checked="" type="radio"/> Anticipated High	<input type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input checked="" type="radio"/> Low Risk	<input type="radio"/> Extremely Low

Hazard Mitigation	<ol style="list-style-type: none"> <li>1. Beam tuning keep activation of magnets to a minimum</li> <li>2. Integrated Safety Management program assures proper work planning prior to authorizing start of work.</li> <li>3. Radiological surveys of work areas performed and RWP issued prior to start of work.</li> <li>4. ALARA design and administrative controls assure doses are well below regulatory limits.</li> <li>5. C-A ALARA Committee reviews.</li> <li>6. Worker/experimenter training.</li> <li>7. Residual radioactivity dose rate levels are very low and radiological postings warn personnel of high dose rates.</li> </ol>
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### Risk Assessment Following Mitigation

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input type="radio"/> Low	<input checked="" type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input checked="" type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input type="radio"/> Low Risk	<input checked="" type="radio"/> Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.  
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

## BAF SAD Appendix 9

Table A9-7  
Qualitative Risk Assessment for BAF – Conventional/Industrial Hazards

FACILITY NAME: BAF

SYSTEM: Entire Facility

SUB-SYSTEM: N/A

HAZARD: Noise, Heat, Confined Spaces, Lasers, Rotating Equipment, Pressurized Systems, Hazardous Atmospheres, Magnetic Fields, Hoisting, Rigging, Heights, Cryogenic Fluids, Chemicals, Flammable/Explosive Gasses, Etc.

Event	Injury resulting from industrial hazard
Possible Consequences, Hazards	Worker/experimenter injury or death.
Potential Initiators	Improper work planning, procedure violation

### Risk Assessment Prior to Mitigation

Note: Refer to Table 4.2.1 for an explanation of consequence, frequency and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	<input checked="" type="radio"/> High	<input type="radio"/> Medium	<input type="radio"/> Low	<input type="radio"/> Extremely Low
Frequency	<input checked="" type="radio"/> Anticipated High	<input type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input checked="" type="radio"/> High Risk	<input type="radio"/> Medium	<input type="radio"/> Low Risk	<input type="radio"/> Extremely Low

Hazard Mitigation	<ol style="list-style-type: none"> <li>1. Integrated Safety Management program assures proper work planning prior to authorizing start of work.</li> <li>2. Worker/experimenter training.</li> <li>3. Review and audit of conventional safety issues by C-A staff and ESH experts during Tier 1, work planning and/or ESH appraisals as required by the BNL Integrated Assessment Program.</li> <li>4. Review of experimental safety by C-A ESRC.</li> <li>5. Safety standards defined by BNL SBMS.</li> <li>6. Environmental review of experiments.</li> <li>7. Industrial hygiene review of experiments.</li> <li>8. Design incorporates requirements of BNL SBMS and industrial standards for conventional and industrial safety.</li> </ol>
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### Risk Assessment Following Mitigation

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input checked="" type="radio"/> Low	<input type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input checked="" type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input checked="" type="radio"/> Low Risk	<input type="radio"/> Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.

Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

## BAF SAD Appendix 9

Table A9-8  
Qualitative Risk Assessment for BAF – Airborne Releases

FACILITY NAME: BAF  
SYSTEM: Ventilation  
SUB-SYSTEM: Exhaust Systems  
HAZARD: Radioactive or Hazardous Materials

Event	Uncontrolled release of airborne radioactive or hazardous materials
Possible Consequences, Hazards	Adverse health effects to workers (public health effects not possible).
Potential Initiators	Improper work planning, violation of procedures, human error

### Risk Assessment Prior to Mitigation

Note: Refer to Table 4.2.1 for an explanation of consequence, frequency and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input checked="" type="radio"/> Low	<input type="radio"/> Extremely Low
Frequency	<input checked="" type="radio"/> Anticipated High	<input type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input checked="" type="radio"/> Low Risk	<input type="radio"/> Extremely Low

Hazard Mitigation	<ol style="list-style-type: none"> <li>1. Integrated Safety Management program assures proper work planning prior to authorizing start of work.</li> <li>2. Worker/experimenter training.</li> <li>3. Review of conventional safety by C-A ASSRC and BNL ESH Committees.</li> <li>4. Review of experimental safety by C-A ESRC.</li> <li>5. Safety standards defined by BNL SBMS.</li> <li>6. BNL Environmental Management System.</li> <li>7. BNL Chemical Management System.</li> <li>8. Testing of HEPA filters and periodic replacement as required by BNL SBMS.</li> <li>9. Design incorporates requirements of BNL SBMS and standards for radiation safety.</li> </ol>
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### Risk Assessment Following Mitigation

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input type="radio"/> Low	<input checked="" type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input checked="" type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input type="radio"/> Low Risk	<input checked="" type="radio"/> Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.  
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

## BAF SAD Appendix 9

Table A9-9  
Qualitative Risk Assessment for BAF – Environmental

FACILITY NAME: BAF  
SYSTEM: Cooling Water System  
SUB-SYSTEM: Radioactive Water  
HAZARD: Soil And Groundwater Contamination

Event	Spill of activated cooling water to soil
Possible Consequences, Hazards	Groundwater contamination, internal dose to BNL personnel or public.
Potential Initiators	Water pressure boundary failure, procedure violation, improper work planning.

### Risk Assessment Prior to Mitigation

Note: Refer to Table 4.2.1 for an explanation of consequence, frequency and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input checked="" type="radio"/> Low	<input type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input checked="" type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input checked="" type="radio"/> Low Risk	<input type="radio"/> Extremely Low

Hazard Mitigation	<ol style="list-style-type: none"> <li>1. Integrated Safety Management program assures proper work planning prior to authorizing start of work.</li> <li>2. Worker/experimenter training.</li> <li>3. Review of conventional safety by C-A ASSRC and BNL ESH Committees.</li> <li>4. Review of experimental safety by C-A ESRC.</li> <li>5. Safety standards defined by BNL SBMS.</li> <li>6. BNL Environmental Management System.</li> <li>7. BNL Chemical Management System.</li> <li>8. Extensive monitoring well system and groundwater-sampling program at BNL.</li> <li>9. BNL site characteristics are well suited for easy groundwater plume characterization. It would take decades for an un-remediated plume to migrate offsite to contaminate a drinking water well. This assures that even if un-remediated, no one would drink contaminated water.</li> <li>10. Periodic replacement of activated water with fresh water to reduce activity levels in water systems.</li> <li>11. Even though tritium levels in cooling water are less than the DWS, the intent of Suffolk County Article 12 Code was followed in the design of cooling water systems and piping that contain trace amounts of tritium.</li> </ol>
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### Risk Assessment Following Mitigation

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input type="radio"/> Low	<input checked="" type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input type="radio"/> Anticipated Medium	<input checked="" type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input type="radio"/> Low Risk	<input checked="" type="radio"/> Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.  
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

## BAF SAD Appendix 9

Table A9-10  
Qualitative Risk Assessment for BAF – Loss of Electrical Power

FACILITY NAME: BAF  
SYSTEM: Entire Facility  
SUB-SYSTEM: N/A  
HAZARD: Hazards Produced As Power Is Lost To Equipment

Event	Loss of offsite power, local loss of power to BAF facility
Possible Consequences, Hazards	Personal safety hazards, programmatic loss
Potential Initiators	Loss of electrical power to BNL site or local power loss to BAF caused by equipment failure or operator error.

### Risk Assessment Prior to Mitigation

Note: Refer to Table 4.2.1 for an explanation of consequence, frequency and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input type="radio"/> Low	<input checked="" type="radio"/> Extremely Low
Frequency	<input checked="" type="radio"/> Anticipated High	<input type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input checked="" type="radio"/> Low Risk	<input type="radio"/> Extremely Low

Hazard Mitigation	<ol style="list-style-type: none"> <li>1. Integrated Safety Management program assures proper work planning prior to authorizing start of work.</li> <li>2. Worker/experimenter training.</li> <li>3. Review of conventional safety by C-A ASSRC and BNL ESH Committees.</li> <li>4. Review of experimental safety by C-A ESRC.</li> <li>5. Backup power supplied to required systems to reduce programmatic impact.</li> <li>6. Accelerator automatically shuts down upon loss of electrical power.</li> <li>7. ACS fail-safe design.</li> <li>8. Emergency lighting.</li> </ol>
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### Risk Assessment Following Mitigation

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input type="radio"/> Low	<input checked="" type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input checked="" type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input type="radio"/> Low Risk	<input checked="" type="radio"/> Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.  
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

## BAF SAD Appendix 9

Table A9-11  
Qualitative Risk Assessment for BAF – Fire

FACILITY NAME: BAF  
SYSTEM: Entire Facility  
SUB-SYSTEM: N/A  
HAZARD: Personal Injury Or Equipment Damage

Event	Magnets, power and control cables, laboratory equipment combustion
Possible Consequences, Hazards	Personal injury, programmatic impact
Potential Initiators	Loss of cooling to magnets or power supplies, transient combustibles start fire which spreads, human error

### Risk Assessment Prior to Mitigation

Note: Refer to Table 4.2.1 for an explanation of consequence, frequency and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	<input checked="" type="radio"/> High	<input type="radio"/> Medium	<input type="radio"/> Low	<input type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input checked="" type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input checked="" type="radio"/> Medium	<input type="radio"/> Low Risk	<input type="radio"/> Extremely Low

Hazard Mitigation	<ol style="list-style-type: none"> <li>1. Low combustible loading exists at facility.</li> <li>2. Periodic safety inspections.</li> <li>3. Safety training for Users and Staff.</li> <li>4. Fire protection/suppression system is designated safety significant. Design reviewed by BNL Fire Protection Engineer. Meets NFPA requirements.</li> <li>5. Emergency ventilation.</li> <li>5. Experiments reviewed by C-A ESRC.</li> <li>6. Conventional safety reviewed by C-A ESRC.</li> <li>7. Fire Hazards Analysis completed for BAF.</li> </ol>
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### Risk Assessment Following Mitigation

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input checked="" type="radio"/> Low	<input type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input checked="" type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input checked="" type="radio"/> Low Risk	<input type="radio"/> Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.  
Is the hazard mitigation system needed for hazard control? Y/N Yes If Yes, need ASE requirement.

## BAF SAD Appendix 9

Table A9-12  
Qualitative Risk Assessment for BAF – Environmental

FACILITY NAME: BAF  
SYSTEM: Soil Shielding  
SUB-SYSTEM: N/A  
HAZARD: Groundwater Contamination

Event	Groundwater contamination from activated soil
Possible Consequences, Hazards	Internal radiation dose, loss of regulator/public confidence.
Potential Initiators	Soil cap failure

### Risk Assessment Prior to Mitigation

Note: Refer to Table 4.2.1 for an explanation of consequence, frequency and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	<input type="radio"/> High	<input checked="" type="radio"/> Medium	<input type="radio"/> Low	<input type="radio"/> Extremely Low
Frequency	<input checked="" type="radio"/> Anticipated High	<input type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input checked="" type="radio"/> High Risk	<input type="radio"/> Medium	<input type="radio"/> Low Risk	<input type="radio"/> Extremely Low

Hazard Mitigation	<ol style="list-style-type: none"> <li>1. Beam tunnel and target room impermeable soil caps.</li> <li>2. Periodic cap inspections.</li> <li>3. Beam tuning procedures.</li> <li>4. Operator/Physicist training.</li> <li>5. BNL Environmental Management System.</li> <li>6. Extensive groundwater monitoring well system and sampling program in place.</li> <li>7. Long travel time for plume to reach BNL site boundary.</li> </ol>
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### Risk Assessment Following Mitigation

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input checked="" type="radio"/> Low	<input type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input checked="" type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input checked="" type="radio"/> Low Risk	<input type="radio"/> Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.  
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

## BAF SAD Appendix 9

Table A9-13  
Qualitative Risk Assessment for BAF – Biological/Medical

FACILITY NAME: BAF  
SYSTEM: Support Building  
SUB-SYSTEM: N/A  
HAZARD: Biological or Medical

Event	Release or contamination by biological or medical hazards
Possible Consequences, Hazards	Illness, programmatic impact
Potential Initiators	Failure to follow procedures, improper review of experiment, equipment failure

### Risk Assessment Prior to Mitigation

Note: Refer to Table 4.2.1 for an explanation of consequence, frequency and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	<input type="radio"/> High	<input checked="" type="radio"/> Medium	<input type="radio"/> Low	<input type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input checked="" type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input checked="" type="radio"/> Medium	<input type="radio"/> Low Risk	<input type="radio"/> Extremely Low

Hazard Mitigation	<ol style="list-style-type: none"> <li>1. Facility designed for Biosafety Level 2, which can safely handle blood, body fluids and tissues infected with unknown agents.</li> <li>2. General public excluded from facility.</li> <li>3. Cell Facility separated from Animal Facility in building. Animal Facility HEPA filtered.</li> <li>4. Regulated Medical Wastes handled by properly trained BNL Medical Department Personnel.</li> <li>5. Biological Safety cabinets used to protect workers and users.</li> <li>6. Training of the user in safe laboratory practices, including engineered systems and PPE, is given by the BNL Medical Department, commensurate with risk to worker.</li> <li>7. Experiments with human cells and tissues reviewed by BNL Institutional Review Board.</li> <li>8. Transportation of cells, animals, etc., to and from the facility, will be in accordance with BNL requirements.</li> <li>9. Review of experiments by appropriate BNL committees, and by C-A ESRC.</li> <li>10. Review of experiment by industrial hygienist and ECR.</li> </ol>
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### Risk Assessment Following Mitigation

Consequence	<input type="radio"/> High	<input type="radio"/> Medium	<input type="radio"/> Low	<input checked="" type="radio"/> Extremely Low
Frequency	<input type="radio"/> Anticipated High	<input checked="" type="radio"/> Anticipated Medium	<input type="radio"/> Unlikely	<input type="radio"/> Extremely Unlikely
Risk Category	<input type="radio"/> High Risk	<input type="radio"/> Medium	<input checked="" type="radio"/> Low Risk	<input type="radio"/> Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.

Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

## Collider-Accelerator Department Shielding Policy

The shielding policy for this facility is that of the Collider-Accelerator Department since the beam line, Target Hall and Support Building are part of the Department's facilities. The main features of this policy are currently delineated in the Collider-Accelerator Department Operations Procedure Manual.<sup>1, 2</sup> The principal components of this policy are reviewed here for completeness.

The primary purpose of the shielding policy is to assure that all radiation related requirements and administrative control levels are satisfied. Specifically, the Collider-Accelerator Department's Radiation Safety Committee reviews facility-shielding configurations to assure:

- Annual site-boundary dose equivalent is less than 5 mrem.
- Annual on-site dose equivalent to inadvertently exposed people in non-Collider-Accelerator Department facilities is less than 25 mrem.
- Maximum dose equivalent to any area where access is not controlled is limited to less than 20 mrem during a fault condition.
- For continuously occupied locations, the dose equivalent rate is ALARA but in no case greater than 0.5 mrem in one hour or 20 mrem in one week.
- Dose equivalent rates where occupancy is not continuous is ALARA, but in no case exceeds 1 rem in one year for whole body radiation, or 3 rem in one year for the lens of the eye, or 10 rem in one year for any organ.

In addition to review and approval by the Radiation Safety Committee, final shield drawings must be approved by the Radiation Safety Committee Chair or the ESHQ Associate Chair. Shield drawings are verified by comparing the drawing to the actual configuration.

Radiation surveys and fault studies are conducted to verify the adequacy of any new or modified shield configuration. The fault study methodology that is used to verify the adequacy of shielding is proscribed by additional Collider-Accelerator Department procedures, which are not elaborated here.<sup>3</sup>

Any modifications to shielding configurations are likewise closely proscribed. The Booster Application Facility, like all Department facilities, is assigned a Liaison Physicist and Liaison Engineer. The Liaison Physicist is responsible, in consultation with the Radiation Safety Committee where appropriate, for determining safe conditions for any shielding modifications. The Liaison Engineer is responsible for ensuring that the safe conditions are met, for effecting any modification, and for notifying other responsible Collider-Accelerator Department personnel, including the Operations Coordinator, as well as experimenters both prior to and on completion of the modifications. Additional procedures exist to ensure that policy with respect to control of radioactive shielding is implemented, which are not elaborated here.

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<sup>1</sup> <http://www.agsrhichome.bnl.gov/AGS/Accel/SND/OPM/Ch09/09-01-12.PDF> Procedure for Review of Collider-Accelerator Department Shielding Design

<sup>2</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch08/08-13.PDF> Collider-Accelerator Department Procedure for Shielding/Barrier Removal, Removal of Primary Area Beam Line Components, or Modifications

<sup>3</sup> <http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch09/09-01-09.PDF> Fault Study Procedure for Primary and Secondary Areas



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managed by Brookhaven Science Associates  
for the U.S. Department of Energy

*date: February 9, 2001*

*to: T. Sheridan and T. Kirk*

*from: D. I. Lowenstein*

*subject: Update to Path for Booster Applications Facility Authorization*

## Memo

As per request by T. Sheridan, the plan for the path forward to authorize Collider-Accelerator Department to commission and operate the Booster Applications Facility was amended to include three additional steps from the Accelerator Safety Subject Area:

Step 18 – Deputy Director for Operations reviews and approves the Routine Operations Package.

Step 19 – Deputy Director for Operations submits advance copies of the final Accelerator Safety Envelope to Brookhaven Area Office for approval.

Step 25 - The Collider-Accelerator Department develops and incorporates an Unreviewed Safety Issues Checklist and procedure into the work planning and control processes for BAF.

The updated plan is attached.

\* \* \*

Copy to:

R. Karol  
P. Kelley  
E. Lessard  
A. McNerney  
P. Pile  
T. Roser

Milestone	Date
1. Collider-Accelerator Department defines path for authorization basis documents with Associate Laboratory Director for High Energy and Nuclear Physics, Deputy Director for Operations and Brookhaven Area Office concurrence	February 15, 2001
2. Collider-Accelerator Department develops Safety Assessment Document and Accelerator Safety Envelope for Booster Applications Facility. The Collider-Accelerator Department Accelerator Systems Safety Review and Radiation Safety Committees review these documents.	April 15, 2001
3. Associate Laboratory Director for High Energy and Nuclear Physics or designee submits Safety Assessment Document/Accelerator Safety Envelope for accelerator facility or module to BNL Environment, Safety and Health Committee	May 10, 2001
4. BNL Environment, Safety and Health Committee reviews and recommends to Deputy Director for Operations approval of Safety Assessment Document and Accelerator Safety Envelope for Booster Applications Facility	June 8, 2001
5. Collider-Accelerator Department develops Commissioning Plan and provides change controlled Commissioning Package to Deputy Director for Operations	April 1, 2002
6. Deputy Director for Operations reviews and approves Commissioning Package and provides advance copies to Brookhaven Area Office	April 15, 2002
7. Collider-Accelerator Department declares readiness for commissioning Booster Applications Facility	May 1, 2002
8. Deputy Director for Operations appoints Accelerator Readiness Review Team, and invites DOE-Brookhaven Area Office to name a member to the Accelerator Readiness Review Team	May 1, 2002
9. Accelerator Readiness Review Team develops Commissioning-specific Plan of Action to guide the Accelerator Readiness Review Team	May 15, 2002
10. Accelerator Readiness Review Team conducts review and recommends approval for commissioning to Deputy Director for Operations	July 1, 2002
11. Deputy Director for Operations forwards Accelerator Readiness Review Team report and any revisions to the Commissioning Package to Brookhaven Area Office and requests approval for commissioning	July 15, 2002

12. Brookhaven Area Office sends approval of Commissioning Package to Deputy Director for Operations; Deputy Director for Operations sends approval to Associate Laboratory Director for High Energy and Nuclear Physics and Collider-Accelerator Department Chair	August 1, 2002
13. Collider-Accelerator Department begins commissioning within boundaries defined in the fully change controlled Commissioning Package	October 1, 2002
14. Collider-Accelerator Department develops final Safety Assessment Document and Accelerator Safety Envelope for operating accelerator facility incorporating appropriate information obtained during commissioning. Due to the size and complexity of the Booster Applications Facility, no significant changes to the documents are expected.	October 1, 2002
15. Associate Laboratory Director for High Energy and Nuclear Physics or designee submits final Safety Assessment Document and Accelerator Safety Envelope to Laboratory Environment, Safety and Health Committee	October 1, 2002
16. Laboratory Environment, Safety and Health Committee reviews and recommends approval of Safety Assessment Document and Accelerator Safety Envelope for facility operations	October 15, 2002
17. Collider-Accelerator Department develops Routine Operations Plan and provides it and change controlled final versions of Safety Assessment Document and Accelerator Safety Envelope to Deputy Director for Operations	October 15, 2002
18. Deputy Director for Operations reviews and approves the Routine Operations Package.	November 1, 2002
19. Deputy Director for Operations submits advance copies of the final Accelerator Safety Envelope to Brookhaven Area Office for approval.	November 1, 2002
20. Collider-Accelerator Department Chair declares readiness for operations per Routine Operations Plan	November 1, 2002
21. Accelerator Readiness Review Team develops final Accelerator Readiness Review Team Plan of Action, conducts Accelerator Readiness Review Team per Plan of Action and recommends approval for routine operations to Deputy Director for Operations. Since the Booster Applications Facility is a straightforward accelerator module, the ARR Team may simply verify that Operational Readiness Review items from the commissioning phase are complete, and verify the Safety Assessment Document and Accelerator Safety Envelope used during commissioning are sufficient for operations	November 1, 2002

22. Deputy Director for Operations forwards change controlled final Safety Assessment Document, Accelerator Safety Envelope, and Accelerator Readiness Review Team report to Brookhaven Area Office and requests approval for operations	November 15, 2002
23. Brookhaven Area Office sends approval of final Accelerator Safety Envelope to Deputy Director for Operations	December 1, 2002
24. Collider-Accelerator Department makes appropriate Facility Use Agreement modifications	December 15, 2002
25. The Collider-Accelerator Department develops and incorporates an Unreviewed Safety Issues Checklist and procedure into work planning and control processes for BAF.	December 24, 2002
26. Deputy Director for Operations sends approval for routine operations to Associate Laboratory Director for High Energy and Nuclear Physics and Collider-Accelerator Department Chair	January 1, 2003



# Memo

*Date:* March 19, 2001 (**Revised 4/19/00**)

*To:* Files

*From:* R. Karol

*Subject:* Dose to Individual in BAF Target Room Following Ventilation Failure

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## **Purpose**

To calculate the dose to an individual in the BAF Target Room from activated air following loss of Target Room Ventilation.

## **Summary and Conclusions**

The dose to an individual following 60 minutes of exposure in the Target Room, after 8 hours of beam operation without ventilation, would be about 0.12 mrem. This level is well below any need to mitigate the dose.

## **Assumptions**

1. Although the Target Room exhaust ventilation is normally on, it is assumed to be off for 8 hours while the beam is at normal intensity.
2. As soon as the beam is turned off, an individual enters the Target Room and remains there for 60 minutes.
3. The external dose from the radioisotopes in the room air, and the internal dose from inhalation of the air is summed to determine the effective dose equivalent. The external dose is found by conservatively assuming a semi-infinite cloud, although the room has a finite volume.
4. A breathing rate of  $9.6 \text{ m}^3$  in 8 hours is assumed.
5. Buildup of radioisotopes in the room air during the 8 hours of beam operation, and decay during the 60 minutes of exposure when the beam is off, is accounted for.
6. BAF operates for 1500 hours per year.

**Input Data**

- The following radioisotope concentrations, decay constants and dose conversion factors were used [1,2,3]. For  $^{39}\text{Cl}$  and  $^{38}\text{Cl}$  production, Rudstram's Formula [4] was used to determine the cross sections, assuming 1 GeV energy protons [5]. These isotopes were considered as a result of a suggestion from the C-A ALARA Chair [6].

**Table 1 - Annual-Activity Concentration Averaged over Target Room Volume and Annual Production Rate of Air Activation Products**

Radionuclide of Interest	Radionuclide Decay Constant, $\text{sec}^{-1}$	Immersion Dose Conversion Factor, mrem/yr per $\mu\text{Ci}/\text{m}^3$	Inhalation Dose Conversion Factor, rem/ $\mu\text{Ci}$	Volume Averaged Annual-Activity Concentration, $\text{Ci}/\text{m}^3$	Annual Production Rate, $\text{Ci}/\text{yr}$
$^{41}\text{Ar}$	$1.5 \times 10^{-4}$	6630	0	$2.2 \times 10^{-5}$	$2.6 \times 10^{-3}$
$^{39}\text{Cl}$	$2.1 \times 10^{-4}$	8590	$1.2 \times 10^{-4}$	$1.2 \times 10^{-10}$	$1.4 \times 10^{-8}$
$^{38}\text{Cl}$	$3.1 \times 10^{-4}$	9190 <sup>1</sup>	$9.7 \times 10^{-5}$	$4.3 \times 10^{-10}$	$4.9 \times 10^{-8}$
$^{35}\text{S}$	$9.2 \times 10^{-8}$	0	$2.3 \times 10^{-3}$	$1.4 \times 10^{-9}$	$1.6 \times 10^{-7}$
$^{32}\text{P}$	$5.6 \times 10^{-7}$	0	$1.3 \times 10^{-2}$	$9.1 \times 10^{-9}$	$1.0 \times 10^{-6}$
$^{28}\text{Al}$	$8.6 \times 10^{-5}$	9920	0	$7.0 \times 10^{-7}$	$8.1 \times 10^{-5}$
$^{22}\text{Na}$	$8.4 \times 10^{-9}$	11200	$8.3 \times 10^{-3}$	$5.6 \times 10^{-11}$	$6.3 \times 10^{-9}$
$^{15}\text{O}$	$5.7 \times 10^{-3}$	5120	0	$6.7 \times 10^{-3}$	$7.4 \times 10^{-1}$
$^{14}\text{O}$	$9.8 \times 10^{-3}$	5110	0	$2.8 \times 10^{-4}$	$3.2 \times 10^{-2}$
$^{13}\text{N}$	$1.2 \times 10^{-3}$	5110	0	$1.6 \times 10^{-3}$	$1.8 \times 10^{-1}$
$^{11}\text{C}$	$5.6 \times 10^{-4}$	5110	$1.2 \times 10^{-5}$	$7.0 \times 10^{-4}$	$8.1 \times 10^{-2}$
$^7\text{Be}$	$1.5 \times 10^{-7}$	249	$2.7 \times 10^{-4}$	$1.9 \times 10^{-7}$	$2.1 \times 10^{-5}$
$^3\text{H}$	$1.8 \times 10^{-9}$	0	$6.3 \times 10^{-5}$	$7.7 \times 10^{-19}$	$8.8 \times 10^{-7}$

**Detailed Calculation and Analyses**

- Since the annual production rate for each isotope was found by ignoring decay, the production rate is found as follows:

$$R_i = 3.7 \times 10^{10} C_i / \lambda_i \text{ atoms/ m}^3\text{-sec}$$

Where  $R_i$  = production rate of radioisotope i

$C_i$  = curies/ $\text{m}^3$  of radioisotope i in the Target Room, Table 1

$\lambda_i$  = radioactive decay constant of isotope i,  $\text{sec}^{-1}$

- With the production rate,  $R_i$ , known for each radioisotope, the number density for each isotope can be found at the end of a beam operating interval as follows:

$$dN_i/dt = R_i - (\lambda_i + \lambda_{i,v})N_i$$

<sup>1</sup> Federal Guidance Report No. 12, EPA 402-R-93-081, September 1993.

## BAF SAD Appendix 12

Where  $N_i$  = atoms/m<sup>3</sup> of radioisotope I  
 $\lambda_{i,v}$  = ventilation decay constant of Target Room = Q/V  
Q = exhaust flow rate of room, ft<sup>3</sup>/sec (assumed to be zero)  
V = room volume, 4000 ft<sup>3</sup>

Solving yields,

$$N_i(t) = \frac{R}{\lambda_i + \lambda_{v,i}} (1 - e^{-(\lambda_i + \lambda_{v,i})t_{on}})$$

3. At the end of 8 hours of operation ( $t_{on}$ ) the number density of each radioisotope is found using the above equation.
4. Once the beam is off, the activity of each isotope decays. The average activity over the 60 minutes ( $t_{off}$ ) of exposure is found as follows:

$$\overline{A} = \frac{\int_0^{t_{off}} A_{io} e^{-(\lambda_i + \lambda_{v,i})t} dt}{t_{off}}$$

5. The external immersion and internal inhalation dose from 30 minutes of exposure are computed, using appropriate units, as follows:

$$H_{int} = \sum_i \overline{A}_i * DCF_{imm,i} * t_{off}$$

$$H_{ext} = \sum_i \overline{A}_i * BR * DCF_{ext,i} * t_{off}$$

6. The code used to compute the 60-minute dose is attached as Appendix 1. The results show a 0.0025 mrem inhalation and a 0.116 immersion dose for a total of 0.12 mrem.

**References**

1. DOE/EH-0071, Internal Dose Conversion Factors for Calculations of Dose to the Public, July 1988.
2. DOE/EH-0070, External Dose Conversion Factors for Calculator of Dose to the Public, July 1988.
3. A. Stevens, Estimates of Radiological Quantities Associated with the Booster Applications Facility, BAF SAD, Chapter 4, Table 4.5.5.a.
4. Barbier, M., *Induced Radioactivity*. Chapter II. 1969.
5. Conversation with A. Stevens, C-A Department Radiation Physicist.
6. C. Schaefer, Recommendations From a Review of the Draft BAF SAD, April 12, 2001.

## BAF SAD Appendix 12

### APPENDIX 1

```
'code for BAF target room dose (inhalation and immersion)
'by rck      2/6/01 (revised 4/18/01 to include C1-39 and C1-38)

DIM lamda(13), c(13), a0(13), r(13), n0(13), aave(13), dcfinh(13), dcfimm(13)
DIM lamdaeff(13), himm(13), hinh(13), n$(13)
br = 9.6 / 8 / 3600: 'breathing rate of 9600 l in 8 hours, units of m3/sec
hinh = 0: himm = 0: CLS
FOR i = 1 TO 13: READ lamda(i): NEXT i: 'radioactive decay constants, 1/sec
INPUT "Room Vent rate in CFM"; vdot: vdot = vdot / 60: 'ft3/sec
v = 4000: 'ft3 room volume
lamdav = vdot / v: 'vent decay constant in 1/sec
FOR i = 1 TO 13: lamdaeff(i) = lamda(i) + lamdav: NEXT i
FOR i = 1 TO 13: READ c(i): NEXT i: 'Ci/m3-yr from A.Stevens calc
FOR i = 1 TO 13: READ dcfimm(i): NEXT i: 'immersion DCF
FOR i = 1 TO 13: READ dcfinh(i): NEXT i: 'inhalation DCF
FOR i = 1 TO 13: READ n$(i): NEXT i: 'isotope names
INPUT "Beam on time (hrs)"; tirr: tirr = tirr * 3600: 'convert to sec
INPUT "Beam off time (minutes)"; toff: toff = toff * 60: 'convert to sec
FOR i = 1 TO 13
    'atoms/m3-sec prod rate (fixed 1500 hours from A. Stevens calc):
    r(i) = c(i) / 5400000! * 3.7E+10 / lamda(i)
    'atoms/m3 after irradiation stops:
    n0(i) = r(i) / lamdaeff(i) * (1 - EXP(-lamdaeff(i) * tirr))
    'dist/m3-sec at toff = 0:
    a0(i) = n0(i) * lamda(i)
    'average activity during beam off interval (microCi/m3):
    a1 = a0(i) / (lamdaeff(i) * toff)
    a2 = (1 - EXP(-lamdaeff(i) * toff))
    aave(i) = a1 * a2 / 37000!
NEXT i
FOR i = 1 TO 13
    'immersion dose in mrem
    himm(i) = aave(i) * dcfimm(i) * toff / 3.15576E+07
    himm = himm + himm(i)
    'inhalation dose in mrem:
    hinh(i) = aave(i) * br * toff * dcfinh(i) * 1000
    hinh = hinh + hinh(i)
NEXT i

'output:
CLS
PRINT "Ventillation rate ="; vdot * 60; "CFM   Target room volume ="; v; "ft3"
PRINT "Beam on time ="; tirr / 3600; "hrs       Beam off time ="; toff * 60;
"min"
PRINT : PRINT "Isotope dose in mrem for inhalation and immersion:"
FOR i = 1 TO 13
    PRINT n$(i), hinh(i), himm(i)
NEXT i
PRINT : PRINT "Total inhalation dose ="; hinh; "mrem"
PRINT "Total immersion dose ="; himm; "mrem"
PRINT : PRINT "Total effective dose ="; (hinh + himm); "mrem"
END

'values of decay constant (lamda) in 1/sec:
DATA 1.502e-4,3.105e-4,2.078e-4,9.2e-8,5.618e-7,8.557e-5,8.448e-9,5.672e-3
DATA 9.818e-3,1.159e-3,5.619e-4,1.506e-7,1.783e-9
'values of activity of isotope at end of 1500 hours without any decay
'units of Ci/m3-yr, where yr = 1500 hours with beam
```

## BAF SAD Appendix 12

```
DATA 2.2e-5,1.2e-10,4.3e-10,1.4e-9,9.1e-9,7e-7,5.6e-11,6.7e-3,2.8e-4,1.6e-3
DATA 7e-4,1.9e-7,7.7e-9
'immersion DCF in mrem/yr per microCi/m3:
DATA 6630,8590,9190,0,0,9920,11200,5120,5110,5110,5110,249,0
'inhhalation DCF in rem/microCi:
DATA 0,1.2e-4,9.7e-5,2.3e-3,1.3e-2,0,8.3e-3,0,0,0,1.2e-5,2.7e-4,6.3e-5
'isotope names:
DATA "Ar-41","Cl-39","Cl-38","S-35","P-32","Al-28","Na-22","O-15","O-14","N-
13","C-11"
DATA "Be-7","H-3"
```